Singularity Wikibook

Contents

Articles

References

Article Licenses

Technological singularity

The **technological singularity** is the theoretical emergence of greater-than-human superintelligence through technological means.[1] Since the capabilities of such intelligence would be difficult for an unaided human mind to comprehend, the occurrence of a technological singularity is seen as an intellectual event horizon, beyond which events cannot be predicted or understood.

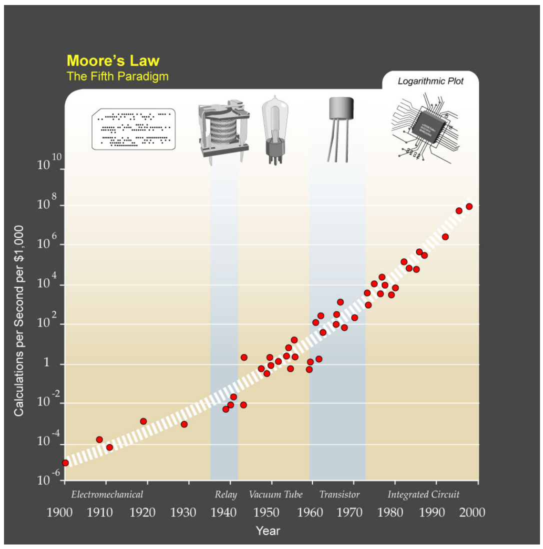
Proponents of the singularity typically state that an "intelligence explosion",[2][3] where superintelligences design successive generations of increasingly powerful minds, might occur very quickly and might not stop until the agent's cognitive abilities greatly surpass that of any human.

The term was popularized by science fiction writer Vernor Vinge, who argues that artificial intelligence, human biological enhancement, or brain-computer interfaces could be possible causes of the singularity. The specific term "singularity" as a description for a phenomenon of technological acceleration causing an eventual unpredictable outcome in society was coined by mathematician John von Neumann, who in the mid 1950s spoke of "ever accelerating progress of technology and changes in the mode of human life, which gives the appearance of approaching some essential singularity in the history of the race beyond which human affairs, as we know them, could not continue." The concept has also been popularized by futurists such as Ray Kurzweil, who cited von Neumann's use of the term in a foreword to von Neumann's classic "The Computer and the Brain."

Some analysts expect the singularity to occur some time in the 21st century, although their estimates vary.

Basic concepts

Many of the most recognized writers on the singularity, such as Vernor Vinge and Ray Kurzweil, define the concept in terms of the technological creation of superintelligence, and argue that it is difficult or impossible for present-day humans to predict what a post-singularity would be like, due to the difficulty of imagining the intentions and capabilities of superintelligent entities.[4][5][6] The term "technological singularity" was originally coined by Vinge, who made an analogy between the breakdown in our ability to predict what would happen after the development of superintelligence and the breakdown of the predictive ability of modern physics at the space-time singularity beyond the event horizon of a black hole.[6]



Kurzweil writes that, due to paradigm shifts, a trend of exponential growth extends Moore's law from integrated circuits to earlier transistors, vacuum tubes, relays, and electromechanical computers. He predicts that the exponential growth will continue, and that in a few decades the computing power of all computers will exceed that of human brains, with superhuman artificial intelligence appearing around the same time.

Some writers use "the singularity" in a broader way to refer to any radical changes in our society brought about by new technologies such as molecular nanotechnology,[7][8][9] although Vinge and other prominent writers specifically state that without superintelligence, such changes would not qualify as a true singularity.[4] Many writers also tie the singularity to observations of exponential growth in various technologies (with Moore's Law being the most prominent example), using such observations as a basis for predicting that the singularity is likely to happen sometime within the 21st century.[8][10]

A technological singularity includes the concept of an intelligence explosion, a term coined in 1965 by I. J. Good.[11] Although technological progress has been accelerating, it has been limited by the basic intelligence of the human brain, which has not, according to Paul R. Ehrlich, changed significantly for millennia.[12] However, with the increasing power of computers and other technologies, it might eventually be possible to build a machine that is more intelligent than humanity.[13] If superhuman intelligences were invented, either through the amplification of human intelligence or artificial intelligence, it would bring to bear greater problem-solving and inventive skills than humans, then it could design a yet more capable machine, or re-write its source code to become more intelligent. This more capable machine could then go on to design a machine of even greater capability. These iterations could accelerate, leading to recursive self-improvement, potentially allowing enormous qualitative change before any upper limits imposed by the laws of physics or theoretical computation set in.[14][15][16]

The exponential growth in computing technology suggested by Moore's Law is commonly cited as a reason to expect a singularity in the relatively near future, and a number of authors have proposed generalizations of Moore's Law. Computer scientist and futurist Hans Moravec proposed in a 1998 book that the exponential growth curve could be extended back through earlier computing technologies prior to the integrated circuit. Futurist Ray Kurzweil postulates a law of accelerating returns in which the speed of technological change (and more generally, all evolutionary processes[17]) increases exponentially, generalizing Moore's Law in the same manner as Moravec's proposal, and also including material technology (especially as applied to nanotechnology), medical technology and others.[18] Like other authors, though, he reserves the term "singularity" for a rapid increase in intelligence (as opposed to other technologies), writing for example that "The Singularity will allow us to transcend these limitations of our biological bodies and brains ... There will be no distinction, post-Singularity, between human and machine".[19] He also defines his predicted date of the singularity (2045) in terms of when he expects computer-based intelligences to significantly exceed the sum total of human brainpower, writing that advances in computing before that date "will not represent the Singularity" because they do "not yet correspond to a profound expansion of our intelligence."[20]

The term "technological singularity" reflects the idea that such change may happen suddenly, and that it is difficult to predict how such a new world would operate.[21][22] It is unclear whether an intelligence explosion of this kind would be beneficial or harmful, or even an existential threat,[23][24] as the issue has not been dealt with by most artificial general intelligence researchers, although the topic of friendly artificial intelligence is investigated by the Singularity Institute for Artificial Intelligence and the Future of Humanity Institute.[21]

Many prominent technologists and academics dispute the plausibility of a technological singularity, including Jeff Hawkins, John Holland, Jaron Lanier, and Gordon Moore, whose Moore's Law is often cited in support of the concept.[25][26]

History of the idea

In the middle of the 19th century Friedrich Engels wrote that science moves forward proportionally to the "mass of knowledge" inherited from the previous generations, he proposed a more formal mathematical concept that, since the 16th century, the development of the sciences had been increasing proportionally to the squared distance in time from its start.

In 1847, R. Thornton, the editor of *The Expounder of Primitive Christianity*,[27] wrote about the recent invention of a four function mechanical calculator:

> ...such machines, by which the scholar may, by turning a crank, grind out the solution of a problem without the fatigue of mental application, would by its introduction into schools, do incalculable injury. But who knows that such machines when brought to greater perfection, may not think of a plan to remedy all their own defects and then grind out ideas beyond the ken of mortal mind!

In 1951, Alan Turing spoke of machines outstripping humans intellectually:[28]

> once the machine thinking method has started, it would not take long to outstrip our feeble powers. ... At some stage therefore we should have to expect the machines to take control, in the way that is mentioned in Samuel Butler's 'Erewhon'.

In the mid fifties Stan Ulam had a conversation with John von Neumann in which von Neumann spoke of "ever accelerating progress of technology and changes in the mode of human life, which gives the appearance of approaching some essential singularity in the history of the race beyond which human affairs, as we know them, could not continue."

In 1965, I. J. Good first wrote of an "intelligence explosion", suggesting that if machines could even slightly surpass human intellect, they could improve their own designs in ways unforeseen by their designers, and thus recursively augment themselves into far greater intelligences. The first such improvements might be small, but as the machine became more intelligent it would become better at becoming more intelligent, which could lead to a cascade of self-improvements and a sudden surge to superintelligence (or a singularity).

In 1983, mathematician and author Vernor Vinge greatly popularized Good’s notion of an intelligence explosion in a number of writings, first addressing the topic in print in the January 1983 issue of *Omni* magazine. In this op-ed piece, Vinge seems to have been the first to use the term "singularity" in a way that was specifically tied to the creation of intelligent machines,[29][30] writing:

> We will soon create intelligences greater than our own. When this happens, human history will have reached a kind of singularity, an intellectual transition as impenetrable as the knotted space-time at the center of a black hole, and the world will pass far beyond our understanding. This singularity, I believe, already haunts a number of science-fiction writers. It makes realistic extrapolation to an interstellar future impossible. To write a story set more than a century hence, one needs a nuclear war in between ... so that the world remains intelligible.

In 1984, Samuel R. Delany used "cultural fugue" as a plot device in his science fiction novel *Stars in My Pocket Like Grains of Sand*; the terminal runaway of technological and cultural complexity in effect destroys all life on any world on which it transpires, a process which is poorly understood by the novel's characters, and against which they seek a stable defense. In 1985 Ray Solomonoff introduced the notion of "infinity point"[31] in the time scale of artificial intelligence, analyzed the magnitude of the "future shock" that "we can expect from our AI expanded scientific community" and on social effects. Estimates were made "for when these milestones would occur, followed by some suggestions for the more effective utilization of the extremely rapid technological growth that is expected."

Vinge also popularized the concept in SF novels such as *Marooned in Realtime* (1986) and *A Fire Upon the Deep* (1992). The former is set in a world of rapidly accelerating change leading to the emergence of more and more sophisticated technologies separated by shorter and shorter time intervals, until a point beyond human comprehension is reached. The latter starts with an imaginative description of the evolution of a superintelligence passing through exponentially accelerating developmental stages ending in a transcendent, almost omnipotent power unfathomable by mere humans. It is also implied that the development does not stop at this level.

In his 1988 book *Mind Children*, computer scientist and futurist Hans Moravec generalizes Moore's law to make predictions about the future of artificial life. Moravec outlines a timeline and a scenario in this regard,[32][33] in that the robots will evolve into a new series of artificial species, starting around 2030-2040.[34] In *Robot: Mere Machine to Transcendent Mind*, published in 1998, Moravec further considers the implications of evolving robot intelligence, generalizing Moore's law to technologies predating the integrated circuit, and speculating about a coming "mind fire" of rapidly expanding superintelligence, similar to Vinge's ideas.

A 1993 article by Vinge, "The Coming Technological Singularity: How to Survive in the Post-Human Era",[4] was widely disseminated on the internet and helped to popularize the idea.[35] This article contains the oft-quoted statement, "Within thirty years, we will have the technological means to create superhuman intelligence. Shortly after, the human era will be ended." Vinge refines his estimate of the time scales involved, adding, "I'll be surprised if this event occurs before 2005 or after 2030."

Vinge predicted four ways the singularity could occur:[36]

1. The development of computers that are "awake" and superhumanly intelligent.
2. Large computer networks (and their associated users) may "wake up" as a superhumanly intelligent entity.
3. Computer/human interfaces may become so intimate that users may reasonably be considered superhumanly intelligent.
4. Biological science may find ways to improve upon the natural human intellect.

Vinge continues by predicting that superhuman intelligences will be able to enhance their own minds faster than their human creators. "When greater-than-human intelligence drives progress," Vinge writes, "that progress will be much more rapid." This feedback loop of self-improving intelligence, he predicts, will cause large amounts of technological progress within a short period, and that the creation of superhuman intelligence represented a breakdown in humans' ability to model their future. His argument was that authors cannot write realistic characters who surpass the human intellect, as the thoughts of such an intellect would be beyond the ability of humans to express. Vinge named this event "the Singularity".

Damien Broderick's popular science book The Spike (1997) was the first to investigate the technological singularity in detail.

In 2000, Bill Joy, a prominent technologist and founder of Sun Microsystems, voiced concern over the potential dangers of the singularity.[37]

In 2005, Ray Kurzweil published *The Singularity is Near*, which brought the idea of the singularity to the popular media both through the book's accessibility and a publicity campaign that included an appearance on *The Daily Show with Jon Stewart*.[38] The book stirred intense controversy, in part because Kurzweil's utopian predictions contrasted starkly with other, darker visions of the possibilities of the singularity. Kurzweil, his theories, and the controversies surrounding it were the subject of Barry Ptolemy's documentary *Transcendent Man*.

In 2007, Eliezer Yudkowsky suggested that many of the different definitions that have been assigned to "singularity" are mutually incompatible rather than mutually supporting.[8] For example, Kurzweil extrapolates current technological trajectories past the arrival of self-improving AI or superhuman intelligence, which Yudkowsky argues represents a tension with both I. J. Good's proposed discontinuous upswing in intelligence and Vinge's thesis on unpredictability.

In 2008, Robin Hanson (taking "singularity" to refer to sharp increases in the exponent of economic growth) lists the Agricultural and Industrial Revolutions as past singularities. Extrapolating from such past events, Hanson proposes that the next economic singularity should increase economic growth between 60 and 250 times. An innovation that allowed for the replacement of virtually all human labor could trigger this event.[39]

In 2009, Kurzweil and X-Prize founder Peter Diamandis announced the establishment of Singularity University, whose stated mission is "to assemble, educate and inspire a cadre of leaders who strive to understand and facilitate the development of exponentially advancing technologies in order to address humanity’s grand challenges."[40] Funded by Google, Autodesk, ePlanet Ventures, and a group of technology industry leaders, Singularity University is based at NASA's Ames Research Center in Mountain View, California. The not-for-profit organization runs an annual ten-week graduate program during the summer that covers ten different technology and allied tracks, and a series of executive programs throughout the year.

In 2010 Aubrey de Grey applied the term the "Methuselarity"[41] to the point at which medical technology improves so fast that expected human lifespan increases by more than one year per year. In 2010 in "Apocalyptic AI - Visions of Heaven in Robotics, Artificial Intelligence, and Virtual Reality"[42] Robert Geraci offers an account of the developing "cyber-theology" inspired by Singularity studies. A book exploring some of those themes is the 1996 Holy Fire by Bruce Sterling, which postulates that a Methuselarity will become a gerontocracy.

In 2011, Kurzweil noted existing trends and concluded that the singularity was becoming more probable to occur around 2045. He told *Time* magazine: "We will successfully reverse-engineer the human brain by the mid-2020s. By

the end of that decade, computers will be capable of human-level intelligence."[43]

Intelligence explosion

The notion of an "intelligence explosion" was first described thus by Good (1965), who speculated on the effects of superhuman machines:

> Let an ultraintelligent machine be defined as a machine that can far surpass all the intellectual activities of any man however clever. Since the design of machines is one of these intellectual activities, an ultraintelligent machine could design even better machines; there would then unquestionably be an ‘intelligence explosion,’ and the intelligence of man would be left far behind. Thus the first ultraintelligent machine is the last invention that man need ever make.

Most proposed methods for creating superhuman or transhuman minds fall into one of two categories, intelligence amplification of human brains and artificial intelligence. The means speculated to produce intelligence augmentation are numerous, and include bioengineering, genetic engineering, nootropic drugs, AI assistants, direct brain-computer interfaces and mind uploading. The existence of multiple paths to an intelligence explosion makes a singularity more likely; for a singularity to not occur they would all have to fail.[6]

Hanson (1998) is skeptical of human intelligence augmentation, writing that once one has exhausted the "low-hanging fruit" of easy methods for increasing human intelligence, further improvements will become increasingly difficult to find. Despite the numerous speculated means for amplifying human intelligence, non-human artificial intelligence (specifically seed AI) is the most popular option for organizations trying to advance the singularity.

Whether or not an intelligence explosion occurs depends on three factors.[44] The first, accelerating factor, is the new intelligence enhancements made possible by each previous improvement. Contrariwise, as the intelligences become more advanced, further advances will become more and more complicated, possibly overcoming the advantage of increased intelligence. Each improvement must be able to beget at least one more improvement, on average, for the singularity to continue. Finally, there is the issue of a hard upper limit. Absent quantum computing, eventually the laws of physics will prevent any further improvements.

There are two logically independent, but mutually reinforcing, accelerating effects: increases in the speed of computation, and improvements to the algorithms used.[45] The former is predicted by Moore’s Law and the forecast improvements in hardware,[46] and is comparatively similar to previous technological advance. On the other hand, most AI researchers believe that software is more important than hardware.

Speed improvements

The first is the improvements to the speed at which minds can be run. Whether human or AI, better hardware increases the rate of future hardware improvements. Oversimplified,[47] Moore's Law suggests that if the first doubling of speed took 18 months, the second would take 18 subjective months; or 9 external months, whereafter, four months, two months, and so on towards a speed singularity.[48] An upper limit on speed may eventually be reached, although it is unclear how high this would be. Hawkins (2008), responding to Good, argued that the upper limit is relatively low;

> Belief in this idea is based on a naive understanding of what intelligence is. As an analogy, imagine we had a computer that could design new computers (chips, systems, and software) faster than itself. Would such a computer lead to infinitely fast computers or even computers that were faster than anything humans could ever build? No. It might accelerate the rate of improvements for a while, but in the end there are limits to how big and fast computers can run. We would end up in the same place; we'd just get there a bit faster. There would be no singularity.
>
> Whereas if it were a lot higher than current human levels of intelligence, the effects of the singularity would be

> enormous enough as to be indistinguishable (to humans) from a singularity with an upper limit. For example, if the speed of thought could be increased a million-fold, a subjective year would pass in 30 physical seconds.[6]

It is difficult to directly compare silicon-based hardware with neurons. But Berglas (2008) notes that computer speech recognition is approaching human capabilities, and that this capability seems to require 0.01% of the volume of the brain. This analogy suggests that modern computer hardware is within a few orders of magnitude of being as powerful as the human brain.

Intelligence improvements

Some intelligence technologies, like seed AI, may also have the potential to make themselves more intelligent, not just faster, by modifying their source code. These improvements would make further improvements possible, which would make further improvements possible, and so on.

This mechanism for an intelligence explosion differs from an increase in speed in two ways. First, it does not require external effect: machines designing faster hardware still require humans to create the improved hardware, or to program factories appropriately. An AI which was rewriting its own source code, however, could do so while contained in an AI box.

Second, as with Vernor Vinge's conception of the singularity, it is much harder to predict the outcome. While speed increases seem to be only a quantitative difference from human intelligence, actual improvements in intelligence would be qualitatively different. Eliezer Yudkowsky compares it to the changes that human intelligence brought: humans changed the world thousands of times more rapidly than evolution had done, and in totally different ways. Similarly, the evolution of life had been a massive departure and acceleration from the previous geological rates of change, and improved intelligence could cause change to be as different again.[49]

There are substantial dangers associated with an intelligence explosion singularity. First, the goal structure of the AI may not be invariant under self-improvement, potentially causing the AI to optimise something other than was intended.[50][51] Secondly, AIs could compete for the scarce resources mankind uses to survive.[52]

While not actively malicious, there is no reason to think that AIs would actively promote human goals unless they could be programmed as such, and if not, might use the resources currently used to support mankind to promote its own goals, causing human extinction.[10][53][54]

Impact

Dramatic changes in the rate of economic growth have occurred in the past because of some technological advancement. Based on population growth, the economy doubled every 250,000 years from the Paleolithic era until the Neolithic Revolution. This new agricultural economy began to double every 900 years, a remarkable increase. In the current era, beginning with the Industrial Revolution, the world's economic output doubles every fifteen years, sixty times faster than during the agricultural era. If the rise of superhuman intelligences causes a similar revolution, argues Robin Hanson, one would expect the economy to double at least quarterly and possibly on a weekly basis.[39]

Existential risk

Berglas (2008) notes that there is no direct evolutionary motivation for an AI to be friendly to humans. Evolution has no inherent tendency to produce outcomes valued by humans, and there is little reason to expect an arbitrary optimisation process to promote an outcome desired by mankind, rather than inadvertently leading to an AI behaving in a way not intended by its creators (such as Nick Bostrom's whimsical example of an AI which was originally programmed with the goal of manufacturing paper clips, so that when it achieves superintelligence it decides to convert the entire planet into a paper clip manufacturing facility;[55][56][57] Anders Sandberg has also elaborated on this scenario, addressing various common counter-arguments.[58]) AI researcher Hugo de Garis suggests that artificial intelligences may simply eliminate the human race for access to scarce resources,[52][59] and humans would

be powerless to stop them.[60] Alternatively, AIs developed under evolutionary pressure to promote their own survival could out compete humanity.[54]

Bostrom (2002) discusses human extinction scenarios, and lists superintelligence as a possible cause:

> When we create the first superintelligent entity, we might make a mistake and give it goals that lead it to annihilate humankind, assuming its enormous intellectual advantage gives it the power to do so. For example, we could mistakenly elevate a subgoal to the status of a supergoal. We tell it to solve a mathematical problem, and it complies by turning all the matter in the solar system into a giant calculating device, in the process killing the person who asked the question.

A significant problem is that unfriendly artificial intelligence is likely to be much easier to create than friendly AI. While both require large advances in recursive optimisation process design, friendly AI also requires the ability to make goal structures invariant under self-improvement (or the AI could transform itself into something unfriendly) and a goal structure that aligns with human values and does not automatically destroy the human race. An unfriendly AI, on the other hand, can optimize for an arbitrary goal structure, which does not need to be invariant under self-modification.[61]

Eliezer Yudkowsky proposed that research be undertaken to produce friendly artificial intelligence in order to address the dangers. He noted that the first real AI would have a head start on self-improvement and, if friendly, could prevent unfriendly AIs from developing, as well as providing enormous benefits to mankind.[53] Bill Hibbard also addresses issues of AI safety and morality in his book *Super-Intelligent Machines*.

One hypothetical approach towards attempting to control an artificial intelligence is an AI box, where the artificial intelligence is kept constrained inside a simulated world and not allowed to affect the external world. However, a sufficiently intelligent AI may simply be able to escape by outsmarting its less intelligent human captors.[21][62][63]

Implications for human society

In 2009, leading computer scientists, artificial intelligence researchers, and roboticists met at the Asilomar Conference Grounds near Monterey Bay in California. The goal was to discuss the potential impact of the hypothetical possibility that robots could become self-sufficient and able to make their own decisions. They discussed the extent to which computers and robots might be able to acquire autonomy, and to what degree they could use such abilities to pose threats or hazards.

Some machines have acquired various forms of semi-autonomy, including the ability to locate their own power sources and choose targets to attack with weapons. Also, some computer viruses can evade elimination and have achieved "cockroach intelligence." The conference attendees noted that self-awareness as depicted in science-fiction is probably unlikely, but that other potential hazards and pitfalls exist.[64]

Some experts and academics have questioned the use of robots for military combat, especially when such robots are given some degree of autonomous functions.[65] A United States Navy report indicates that, as military robots become more complex, there should be greater attention to implications of their ability to make autonomous decisions.[66][67]

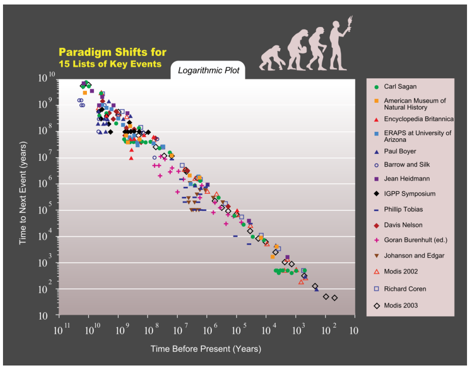
The Association for the Advancement of Artificial Intelligence has commissioned a study to examine this issue,[68] pointing to programs like the Language Acquisition Device, which can emulate human interaction.

Some support the design of friendly artificial intelligence, meaning that the advances which are already occurring with AI should also include an effort to make AI intrinsically friendly and humane.[69]

Isaac Asimov's Three Laws of Robotics is one of the earliest examples of proposed safety measures for AI. The laws are intended to prevent artificially intelligent robots from harming humans. In Asimov's stories, any perceived problems with the laws tend to arise as a result of a misunderstanding on the part of some human operator; the robots themselves are merely acting to their best interpretation of their rules. In the 2004 film *I, Robot*, loosely based on Asimov's *Robot* stories, an AI attempts to take complete control over humanity for the purpose of protecting

humanity from itself due to an extrapolation of the Three Laws. In 2004, the Singularity Institute launched an Internet campaign called *3 Laws Unsafe* to raise awareness of AI safety issues and the inadequacy of Asimov’s laws in particular.[70]

Accelerating change



According to Kurzweil, his logarithmic graph of 15 lists of paradigm shifts for key historic events shows an exponential trend. The lists' compilers include Carl Sagan, Paul D. Boyer, *Encyclopædia Britannica*, American Museum of Natural History, and University of Arizona. Click to enlarge.

Some singularity proponents argue its inevitability through extrapolation of past trends, especially those pertaining to shortening gaps between improvements to technology. In one of the first uses of the term "singularity" in the context of technological progress, Stanislaw Ulam (1958) tells of a conversation with John von Neumann about accelerating change:

> One conversation centered on the ever accelerating progress of technology and changes in the mode of human life, which gives the appearance of approaching some essential singularity in the history of the race beyond which human affairs, as we know them, could not continue.

Hawkins (1983) writes that "mindsteps", dramatic and irreversible changes to paradigms or world views, are accelerating in frequency as quantified in his mindstep equation. He cites the inventions of writing, mathematics, and the computer as examples of such changes.

Kurzweil's analysis of history concludes that technological progress follows a pattern of exponential growth, following what he calls the "Law of Accelerating Returns". Whenever technology approaches a barrier, Kurzweil writes, new technologies will surmount it. He predicts paradigm shifts will become increasingly common, leading to "technological change so rapid and profound it represents a rupture in the fabric of human history".[71] Kurzweil believes that the singularity will occur before the end of the 21st century, setting the date at 2045.[72] His predictions differ from Vinge’s in that he predicts a gradual ascent to the singularity, rather than Vinge’s rapidly self-improving superhuman intelligence.

Presumably, a technological singularity would lead to rapid development of a Kardashev Type I civilization, one that has achieved mastery of the resources of its home planet.[73]

Oft-cited dangers include those commonly associated with molecular nanotechnology and genetic engineering. These threats are major issues for both singularity advocates and critics, and were the subject of Bill Joy's *Wired* magazine article "Why the future doesn't need us".[74]

The Acceleration Studies Foundation, an educational non-profit foundation founded by John Smart, engages in outreach, education, research and advocacy concerning accelerating change.[75] It produces the Accelerating Change conference at Stanford University, and maintains the educational site Acceleration Watch [76].

Criticisms

Some critics assert that no computer or machine will ever achieve human intelligence, while others hold that the definition of intelligence is irrelevant if the net result is the same.[77]

Steven Pinker stated in 2008,

> "(...) There is not the slightest reason to believe in a coming singularity. The fact that you can visualize a future in your imagination is not evidence that it is likely or even possible. Look at domed cities, jet-pack commuting, underwater cities, mile-high buildings, and nuclear-powered automobiles — all staples of futuristic fantasies when I was a child that have never arrived. Sheer processing power is not a pixie dust that magically solves all your problems. (...)"[25]

Martin Ford in *The Lights in the Tunnel: Automation, Accelerating Technology and the Economy of the Future*[78] postulates a "technology paradox" in that before the singularity could occur most routine jobs in the economy would be automated, since this would require a level of technology inferior to that of the singularity. This would cause massive unemployment and plummeting consumer demand, which in turn would destroy the incentive to invest in the technologies that would be required to bring about the Singularity. Job displacement is increasingly no longer limited to work traditionally considered to be "routine."[79]

Jared Diamond, in *Collapse: How Societies Choose to Fail or Succeed*, argues that cultures self-limit when they exceed the sustainable carrying capacity of their environment, and the consumption of strategic resources (frequently timber, soils or water) creates a deleterious positive feedback loop that leads eventually to social collapse and technological retrogression.

Theodore Modis[80][81] and Jonathan Huebner[82] argue that the rate of technological innovation has not only ceased to rise, but is actually now declining (John Smart, however, criticizes Huebner's analysis[83]). Evidence for this decline is that the rise in computer clock rates is slowing, even while Moore's prediction of exponentially increasing circuit density continues to hold. This is due to excessive heat build-up from the chip, which cannot be dissipated quickly enough to prevent the chip from melting when operating at higher speeds. Advancements in speed may be possible in the future by virtue of more power-efficient CPU designs and multi-cell processors.[84] While Kurzweil used Modis' resources, and Modis' work was around accelerating change, Modis distanced himself from Kurzweil's thesis of a "technological singularity", claiming that it lacks scientific rigor.[81]

Others propose that other "singularities" can be found through analysis of trends in world population, world gross domestic product, and other indices. Andrey Korotayev and others argue that historical hyperbolic growth curves can be attributed to feedback loops that ceased to affect global trends in the 1970s, and thus hyperbolic growth should not be expected in the future.[85][86]

In *The Progress of Computing*, William Nordhaus argued that, prior to 1940, computers followed the much slower growth of a traditional industrial economy, thus rejecting extrapolations of Moore's law to 19th-century computers. Schmidhuber (2006) suggests differences in memory of recent and distant events create an illusion of accelerating change, and that such phenomena may be responsible for past apocalyptic predictions.

Andrew Kennedy, in his 2006 paper for the British Interplanetary Society discussing change and the growth in space travel velocities,[87] stated that although long-term overall growth is inevitable, it is small, embodying both ups and downs, and noted, "New technologies follow known laws of power use and information spread and are obliged to connect with what already exists. Remarkable theoretical discoveries, if they end up being used at all, play their part in maintaining the growth rate: they do not make its plotted curve... redundant." He stated that exponential growth is no predictor in itself, and illustrated this with examples such as quantum theory. The quantum was conceived in 1900, and quantum theory was in existence and accepted approximately 25 years later. However, it took over 40 years for Richard Feynman and others to produce meaningful numbers from the theory. Bethe understood nuclear fusion in 1935, but 75 years later fusion reactors are still only used in experimental settings. Similarly, quantum entanglement was understood in 1935 but not at the point of being used in practice until the 21st century.

A study of patents per thousand persons shows that human creativity does not show accelerating returns, but in fact, as suggested by Joseph Tainter in his seminal *The Collapse of Complex Societies*,[88] a law of diminishing returns. The number of patents per thousand peaked in the period from 1850–1900, and has been declining since.[82] The growth of complexity eventually becomes self-limiting, and leads to a widespread "general systems collapse".

In addition to general criticisms of the singularity concept, several critics have raised issues with Kurzweil's iconic chart. One line of criticism is that a log-log chart of this nature is inherently biased toward a straight-line result. Others identify selection bias in the points that Kurzweil chooses to use. For example, biologist PZ Myers points out that many of the early evolutionary "events" were picked arbitrarily.[89] Kurzweil has rebutted this by charting evolutionary events from 15 neutral sources, and showing that they fit a straight line on a log-log chart. *The Economist* mocked the concept with a graph extrapolating that the number of blades on a razor, which has increased over the years from one to as many as five, will increase ever-faster to infinity.[90]

In popular culture

Isaac Asimov's 1950 story "The Evitable Conflict", (the last part of the *I, Robot* collection) features the Machines, four supercomputers managing the world's economy. The computers are incomprehensible to humans and are impossible to analyze for errors, having been created through 10 stages of bootstrapping. In the end of the story, it is implied that from now on (it occurs in 2052), no major conflict can occur, and the Machines are going to guide humanity toward a better future, one only they are capable of seeing (and know to truly be the best). Susan Calvin states that "For all time, all conflicts are finally evitable. Only the Machines, from now on, are inevitable!"

James P. Hogan's 1979 novel *The Two Faces of Tomorrow* is an explicit description of what is now called the Singularity. An artificial intelligence system solves an excavation problem on the moon in a brilliant and novel way, but nearly kills a work crew in the process. Realizing that systems are becoming too sophisticated and complex to predict or manage, a scientific team sets out to teach a sophisticated computer network how to think more humanly. The story documents the rise of self-awareness in the computer system, the humans' loss of control and failed attempts to shut down the experiment as the computer desperately defends itself, and the computer intelligence reaching maturity.

While discussing the singularity's growing recognition, Vernor Vinge wrote in 1993 that "it was the science-fiction writers who felt the first concrete impact." In addition to his own short story "Bookworm, Run!", whose protagonist is a chimpanzee with intelligence augmented by a government experiment, he cites Greg Bear's novel *Blood Music* (1983) as an example of the singularity in fiction. Vinge described surviving the singularity in his 1986 novel *Marooned in Realtime*. Vinge later expanded the notion of the singularity to a galactic scale in *A Fire Upon the Deep* (1992), a novel populated by transcendent beings, each the product of a different race and possessed of distinct agendas and overwhelming power.

In William Gibson's 1984 novel *Neuromancer*, artificial intelligences capable of improving their own programs are strictly regulated by special "Turing police" to ensure they never exceed a certain level of intelligence, and the plot centers on the efforts of one such AI to circumvent their control. The 1994 novel *The Metamorphosis of Prime Intellect* features an AI that augments itself so quickly as to gain low-level control of all matter in the universe in a matter of hours.

William Gibson and Bruce Sterling's alternate history Steampunk novel *The Difference Engine* ends with a vision of the singularity occurring in 1991 with a superintelligent computer that has merged its mind with the inhabitants of London.

A more malevolent AI achieves similar levels of omnipotence in Harlan Ellison's short story *I Have No Mouth, and I Must Scream* (1967).

William Thomas Quick's novels *Dreams of Flesh and Sand* (1988), *Dreams of Gods and Men* (1989), and *Singularities* (1990) present an account of the transition through the singularity; in the last novel, one of the

characters states that mankind's survival requires it to integrate with the emerging machine intelligences, or it will be crushed under the dominance of the machines – the greatest risk to the survival of a species reaching this point (and alluding to large numbers of other species that either survived or failed this test, although no actual contact with alien species occurs in the novels).

The singularity is sometimes addressed in fictional works to explain the event's absence. Neal Asher's *Gridlinked* series features a future where humans living in the Polity are governed by AIs and while some are resentful, most believe that they are far better governors than any human. In the fourth novel, *Polity Agent*, it is mentioned that the singularity is far overdue yet most AIs have decided not to partake in it for reasons that only they know. A flashback character in Ken MacLeod's 1998 novel *The Cassini Division* dismissively refers to the singularity as "the Rapture for nerds", though the singularity goes on to happen anyway.

Popular movies in which computers become intelligent and violently overpower the human race include *Colossus: The Forbin Project*, the *Terminator* series, the very loose film adaptation of *I, Robot*, and *The Matrix* series. The television series *Battlestar Galactica* also explores these themes.

Isaac Asimov expressed ideas similar to a post-Kurzweilian singularity in his short story "The Last Question". Asimov's future envisions a reality where a combination of strong artificial intelligence and post-humans consume the cosmos, during a time Kurzweil describes as when "the universe wakes up", the last of his six stages of cosmic evolution as described in *The Singularity is Near*. Post-human entities throughout various time periods of the story inquire of the artificial intelligence within the story as to how entropy death will be avoided. The AI responds that it lacks sufficient information to come to a conclusion, until the end of the story when the AI does indeed arrive at a solution. Notably, it does so in order to fulfill its duty to answer the humans' question.

St. Edward's University chemist Eamonn Healy discusses accelerating change in the film *Waking Life*. He divides history into increasingly shorter periods, estimating "two billion years for life, six million years for the hominid, a hundred-thousand years for mankind as we know it". He proceeds to human cultural evolution, giving time scales of ten thousand years for agriculture, four hundred years for the scientific revolution, and one hundred fifty years for the industrial revolution. Information is emphasized as providing the basis for the new evolutionary paradigm, with artificial intelligence its culmination. He concludes we will eventually create "neohumans" which will usurp humanity’s present role in scientific and technological progress and allow the exponential trend of accelerating change to continue past the limits of human ability.

Accelerating progress features in some science fiction works, and is a central theme in Charles Stross's *Accelerando*. Other notable authors that address singularity-related issues include Karl Schroeder, Greg Egan, Ken MacLeod, Rudy Rucker, David Brin, Iain M. Banks, Neal Stephenson, Tony Ballantyne, Bruce Sterling, Dan Simmons, Damien Broderick, Fredric Brown, Jacek Dukaj, Stanislav Lem, Nagaru Tanigawa, Douglas Adams, Michael Crichton and Ian McDonald.

The feature-length documentary film *Transcendent Man* by Barry Ptolemy is based on Kurzweil and his book *The Singularity Is Near*. The film documents Kurzweil's quest to reveal what he believes to be mankind's destiny. Another documentary, *Plug & Pray*, focuses on the promise, problems and ethics of artificial intelligence and robotics, with Joseph Weizenbaum and Kurzweil as the main subjects of the film.[91]

In 2009, scientists at Aberystwyth University in Wales and the U.K's University of Cambridge designed a robot called Adam that they believe to be the first machine to independently discover new scientific findings.[92] Also in 2009, researchers at Cornell developed a computer program that extrapolated the laws of motion from a pendulum's swings.[93][94]

The web comic Dresden Codak deals with trans-humanistic themes and the singularity.

The plot of an episode of the TV program *The Big Bang Theory* (season 4, episode 2, "The Cruciferous Vegetable Amplification") revolves around the anticipated date of the coming Singularity.

The seventeenth episode of the sixth season of the TV sitcom Futurama, Benderama references Bender reaching the technological singularity and being able to infinitely produce smaller versions of himself to wreak havoc on the world.

Industrial/Steampunk entertainer Doctor Steel weaves the concept of a technological singularity into his music and videos, even having a song entitled *The Singularity*. He has been interviewed on his views by the Institute for Ethics and Emerging Technologies,[95] and has also authored a paper on the subject.[96][97]

In 2012, concept band SOLA-MI [98], released "NEXUS (Original Motion Picture Soundtrack)," an album about the first waking machine.

In the sci-fi webseries Sync [99], a computer virus takes over a computerized human and becomes a singularity.

Notes

[1] Superintelligence. Answer to the 2009 EDGE QUESTION: "WHAT WILL CHANGE EVERYTHING?": http://www.nickbostrom.com/views/superintelligence.pdf

[2] David Chalmers on Singularity, Intelligence Explosion. April 8th, 2010. Singularity Institute for Artificial Intelligence: http://singinst.org/blog/2010/04/08/david-chalmers-on-singularity-intelligence-explosion/

[3] Editor's Blog Why an Intelligence Explosion is Probable By: Richard Loosemore and Ben Goertzel. March 7, 2011; hplusmagazine: http://hplusmagazine.com/2011/03/07/why-an-intelligence-explosion-is-probable/

[4] Vinge, Vernor. "The Coming Technological Singularity: How to Survive in the Post-Human Era" (http://www-rohan.sdsu.edu/faculty/vinge/misc/singularity.html), originally in *Vision-21: Interdisciplinary Science and Engineering in the Era of Cyberspace*, G. A. Landis, ed., NASA Publication CP-10129, pp. 115-126, 1993

[5] Ray Kurzweil, The Singularity is Near, pp. 135-136. Penguin Group, 2005.

[6] "What is the Singularity? | Singularity Institute for Artificial Intelligence" (http://singinst.org/overview/whatisthesingularity). Singinst.org. . Retrieved 2011-09-09.

[7] "h+ Magazine | Covering technological, scientific, and cultural trends that are changing human beings in fundamental ways" (http://www.hplusmagazine.com/articles/nano/singularity-nanotech-or-ai). Hplusmagazine.com. . Retrieved 2011-09-09.

[8] Yudkowsky, Eliezer. The Singularity: Three Major Schools (http://yudkowsky.net/singularity/schools)

[9] Sandberg, Anders. An overview of models of technological singularity (http://agi-conf.org/2010/wp-content/uploads/2009/06/agi10singmodels2.pdf)

[10] "Max More and Ray Kurzweil on the Singularity" (http://www.kurzweilai.net/max-more-and-ray-kurzweil-on-the-singularity-2). KurzweilAI. . Retrieved 2011-09-09.

[11] Good, I. J. "Speculations Concerning the First Ultraintelligent Machine" (http://www.stat.vt.edu/tech_reports/2005/GoodTechReport.pdf), *Advances in Computers*, vol. 6, 1965.

[12] Ehrlich, Paul. The Dominant Animal: Human Evolution and the Environment (http://www.longnow.org/seminars/02008/jun/27/dominant-animal-human-evolution-and-environment/)

[13] Superbrains born of silicon will change everything. (http://www.businessweek.com/1999/99_35/b3644021.htm)

[14] Good, I. J., "Speculations Concerning the First Ultraintelligent Machine", Franz L. Alt and Morris Rubinoff, ed., Advances in Computers (Academic Press) 6: 31–88, 1965.

[15] The Human Importance of the Intelligence Explosion (http://www.acceleratingfuture.com/people-blog/2007/the-human-importance-of-the-intelligence-explosion/)

[16] Good, I. J. 1965 Speculations Concerning the First Ultraintelligent Machine. Pp 31-88 in Advances in Computers, 6, F. L. Alt and M Rubinoff, eds. New York: Academic Press.

[17] Ray Kurzweil, *The Age of Spiritual Machines*, Viking, 1999, p. 30 (http://books.google.com/books?id=ldAGcyh0bkUC&lpg=PP1&pg=PA630#v=onepage&q&f=false) and p. 32 (http://books.google.com/books?id=ldAGcyh0bkUC&lpg=PP1&pg=PA632#v=onepage&q&f=false)

[18] Ray Kurzweil, *The Singularity is Near*, Penguin Group, 2005

[19] Ray Kurzweil, The Singularity is Near, p. 9. Penguin Group, 2005

[20] Ray Kurzweil, *The Singularity is Near*, pp. 135-136. Penguin Group, 2005. The context for this statement is as follows: "we will be producing about 10^{26} to 10^{29} cps of nonbiological computation per year in the early 2030s. This is roughly equal to our estimate for the capacity of all living biological human intelligence ... This state of computation in the early 2030s will not represent the Singularity, however, because it does not yet correspond to a profound expansion of our intelligence. By the mid-2040s, however, that one thousand dollars' worth of computation will be equal to 10^{26} cps, so the intelligence created per year (at a total cost of about $\$10^{12}$) will be about one billion times more powerful than all human intelligence today. That *will* indeed represent a profound change, and it is for that reason that I set the date for the Singularity—representing a profound and disruptive transformation in human capability—as 2045."

[21] Yudkowsky, Eliezer (2008), Bostrom, Nick; Cirkovic, Milan, eds., "Artificial Intelligence as a Positive and Negative Factor in Global Risk" (http://singinst.org/AIRisk.pdf), *Global Catastrophic Risks* (Oxford University Press): 303, Bibcode 2008gcr..book..303Y,

ISBN 978-0-19-857050-9,

[22] The Uncertain Future; a future technology and world-modeling project (http://www.theuncertainfuture.com/)

[23] GLOBAL CATASTROPHIC RISKS SURVEY (2008) Technical Report 2008/1 Published by Future of Humanity Institute, Oxford University. Anders Sandberg and Nick Bostrom (http://www.fhi.ox.ac.uk/__data/assets/pdf_file/0020/3854/global-catastrophic-risks-report.pdf)

[24] Existential Risks; Analyzing Human Extinction Scenarios and Related Hazards, Nick Bostrom (http://www.nickbostrom.com/existential/risks.html)

[25] "Tech Luminaries Address Singularity - IEEE Spectrum" (http://spectrum.ieee.org/computing/hardware/tech-luminaries-address-singularity). Spectrum.ieee.org. . Retrieved 2011-09-09.

[26] "Who's Who In The Singularity - IEEE Spectrum" (http://spectrum.ieee.org/computing/hardware/whos-who-in-the-singularity). Spectrum.ieee.org. . Retrieved 2011-09-09.

[27] Thornton, Richard (1847), *The Expounder of Primitive Christianity* (http://books.google.com/?id=ZM_hAAAAMAAJ&dq="Primitive Expounder" thornton 1847&pg=PA281#v=onepage&q=thinking machine&f=false), **4**, Ann Arbor, Michigan, p. 281,

[28] A M Turing, *Intelligent Machinery, A Heretical Theory*, 1951, reprinted *Philosophia Mathematica* (1996) 4(3): 256-260 doi:10.1093/philmat/4.3.256 (http://philmat.oxfordjournals.org/content/4/3/256.full.pdf)

[29] Dooling, Richard. *Rapture for the Geeks: When AI Outsmarts IQ* (2008), p. 88 (http://books.google.com/books?id=VbBRsv1lxsUC&lpg=PP1&pg=PA88#v=onepage&q&f=false)

[30] Vinge did not actually use the phrase "technological singularity" in the Omni op-ed, but he did use this phrase in the short story collection *Threats and Other Promises* from 1988, writing in the introduction to his story "The Whirligig of Time" (p. 72): *Barring a worldwide catastrophe, I believe that technology will achieve our wildest dreams, and* soon. *When we raise our own intelligence and that of our creations, we are no longer in a world of human-sized characters. At that point we have fallen into a technological "black hole," a technological singularity.*

[31] Solomonoff, R.J. "The Time Scale of Artificial Intelligence: Reflections on Social Effects," Human Systems Management, Vol 5, pp. 149-153, 1985, http://world.std.com/~rjs/timesc.pdf.

[32] Moravec, Hans (1998), "When will computer hardware match the human brain?" (http://www.transhumanist.com/volume1/moravec.htm), *Journal of Evolution and Technology* **1**, , retrieved 2006-06-23.

[33] Moravec, Hans (June 1993). "The Age of Robots" (http://www.frc.ri.cmu.edu/~hpm/project.archive/general.articles/1993/Robot93.html). . Retrieved 2006-06-23.

[34] Moravec, Hans (April 2004). "Robot Predictions Evolution" (http://www.frc.ri.cmu.edu/~hpm/project.archive/robot.papers/2004/Predictions.html). . Retrieved 2006-06-23.

[35] Dooling, Richard. *Rapture for the Geeks: When AI Outsmarts IQ* (2008), p. 89 (http://books.google.com/books?id=VbBRsv1lxsUC&lpg=PP1&pg=PA89#v=onepage&q&f=false)

[36] The Coming Technological Singularity: How to Survive in the Post-Human Era (http://www-rohan.sdsu.edu/faculty/vinge/misc/singularity.html), by Vernor Vinge, Department of Mathematical Sciences, San Diego State University, (c) 1993 by Vernor Vinge.

[37] Joy, Bill (April 2000), "Why the future doesn't need us" (http://www.wired.com/wired/archive/8.04/joy.html), *Wired Magazine* (Viking Adult) (8.04), ISBN 0-670-03249-2, , retrieved 2007-08-07

[38] *Episode dated 23 August 2006* (http://www.imdb.com/title/tt847969/) at the Internet Movie Database

[39] Robin Hanson, "Economics Of The Singularity" (http://www.spectrum.ieee.org/robotics/robotics-software/economics-of-the-singularity), *IEEE Spectrum Special Report: The Singularity*, , retrieved 2008-09-11 & Long-Term Growth As A Sequence of Exponential Modes (http://hanson.gmu.edu/longgrow.pdf)

[40] About Singularity University (http://singularityu.org/about/) at its official website

[41] de Grey, Aubrey. The singularity and the Methuselarity: similarities and differences (http://www.sens.org/files/sens/FHTI07-deGrey.pdf)

[42] Geraci, Robert M., *Apocalyptic AI - Visions of Heaven in Robotics, Artificial Intelligence, and Virtual Reality*, ISBN 978-0-19-539302-6

[43] 2045: The Year Man Becomes Immortal (http://www.time.com/time/magazine/article/0,9171,2048299,00.html), By Lev Grossman Thursday, Feb. 10, 2011 time.com.

[44] (http://www.fhi.ox.ac.uk/news/2010/david_chalmers_singularity_lecture_resources_available) David Chalmers John Locke Lecture, 10 May, Exam Schools, Oxford, presenting a philosophical analysis of the possibility of a technological singularity or "intelligence explosion" resulting from recursively self-improving AI.

[45] The Singularity: A Philosophical Analysis, David J. Chalmers (http://consc.net/papers/singularity.pdf)

[46] "ITRS" (http://www.itrs.net/Links/2007ITRS/ExecSum2007.pdf) (PDF). . Retrieved 2011-09-09.

[47] Siracusa, John (2009-08-31). "Mac OS X 10.6 Snow Leopard: the Ars Technica review" (http://arstechnica.com/apple/reviews/2009/08/mac-os-x-10-6.ars/8). Arstechnica.com. . Retrieved 2011-09-09.

[48] Eliezer Yudkowsky, 1996 "Staring at the Singularity

[49] Eliezer S. Yudkowsky. "Power of Intelligence" (http://yudkowsky.net/singularity/power). Yudkowsky. . Retrieved 2011-09-09.

[50] Omohundro, Stephen M., "The Basic AI Drives." Artificial General Intelligence, 2008 proceedings of the First AGI Conference, eds. Pei Wang, Ben Goertzel, and Stan Franklin. Vol. 171. Amsterdam: IOS, 2008 (http://selfawaresystems.com/2007/11/30/paper-on-the-basic-ai-drives/)

[51] "Artificial General Intelligence: Now Is the Time" (http://www.kurzweilai.net/artificial-general-intelligence-now-is-the-time). KurzweilAI. . Retrieved 2011-09-09.

[52] Omohundro, Stephen M., "The Nature of Self-Improving Artificial Intelligence." Self-Aware Systems. 21 Jan. 2008. Web. 07 Jan. 2010. (http://selfawaresystems.com/2007/10/05/paper-on-the-nature-of-self-improving-artificial-intelligence/)

[53] "Concise Summary | Singularity Institute for Artificial Intelligence" (http://singinst.org/riskintro/index.html). Singinst.org. . Retrieved 2011-09-09.

[54] Bostrom, Nick, The Future of Human Evolution, Death and Anti-Death: Two Hundred Years After Kant, Fifty Years After Turing, ed. Charles Tandy, p. 339–371, 2004, Ria University Press. (http://www.nickbostrom.com/fut/evolution.html)

[55] Ethical Issues in Advanced Artificial Intelligence, Nick Bostrom, in Cognitive, Emotive and Ethical Aspects of Decision Making in Humans and in Artificial Intelligence, Vol. 2, ed. I. Smit et al., Int. Institute of Advanced Studies in Systems Research and Cybernetics, 2003, pp. 12-17 (http://www.nickbostrom.com/ethics/ai.html)

[56] Eliezer Yudkowsky: Artificial Intelligence as a Positive and Negative Factor in Global Risk (http://singinst.org/upload/artificial-intelligence-risk.pdf). Draft for a publication in *Global Catastrophic Risk* from August 31, 2006, retrieved July 18, 2011 (PDF file)

[57] The Stamp Collecting Device, Nick Hay (http://www.singinst.org/blog/2007/06/11/the-stamp-collecting-device/)

[58] 'Why we should fear the Paperclipper' (http://www.aleph.se/andart/archives/2011/02/why_we_should_fear_the_paperclipper.html), 2011-02-14 entry of Sandberg's blog 'Andart'

[59] Omohundro, Stephen M., "The Basic AI Drives." Artificial General Intelligence, 2008 proceedings of the First AGI Conference, eds. Pei Wang, Ben Goertzel, and Stan Franklin. Vol. 171. Amsterdam: IOS, 2008. (http://selfawaresystems.com/2007/11/30/paper-on-the-basic-ai-drives/)

[60] de Garis, Hugo. "The Coming Artilect War" (http://www.forbes.com/2009/06/18/cosmist-terran-cyborgist-opinions-contributors-artificial-intelligence-09-hugo-de-garis.html), Forbes.com, 22 June 2009.

[61] Coherent Extrapolated Volition, Eliezer S. Yudkowsky, May 2004 (http://singinst.org/upload/CEV.html)

[62] Artificial Intelligence Will Kill Our Grandchildren (Singularity), Dr Anthony Berglas (http://berglas.org/Articles/AIKillGrandchildren/AIKillGrandchildren.html#mozTocId817119)

[63] The Singularity: A Philosophical Analysis David J. Chalmers

[64] Scientists Worry Machines May Outsmart Man (http://www.nytimes.com/2009/07/26/science/26robot.html?_r=1&ref=todayspaper) By JOHN MARKOFF, NY Times, July 26, 2009.

[65] Call for debate on killer robots (http://news.bbc.co.uk/2/hi/technology/8182003.stm), By Jason Palmer, Science and technology reporter, BBC News, 8/3/09.

[66] Mick, Jason. New Navy-funded Report Warns of War Robots Going "Terminator" (http://www.dailytech.com/New Navyfunded Report Warns of War Robots Going Terminator/article14298.htm), Blog, dailytech.com, February 17, 2009.

[67] Flatley, Joseph L. Navy report warns of robot uprising, suggests a strong moral compass (http://www.engadget.com/2009/02/18/navy-report-warns-of-robot-uprising-suggests-a-strong-moral-com/), engadget.com, 18 February 2009.

[68] AAAI Presidential Panel on Long-Term AI Futures 2008-2009 Study (http://research.microsoft.com/en-us/um/people/horvitz/AAAI_Presidential_Panel_2008-2009.htm), Association for the Advancement of Artificial Intelligence, Accessed 7/26/09.

[69] Article at Asimovlaws.com (http://www.asimovlaws.com/articles/archives/2004/07/why_we_need_fri_1.html), July 2004, accessed 7/27/2009.

[70] (Singularity Institute for Artificial Intelligence 2004)

[71] (Kurzweil 2001)

[72] (Kurzweil 2005)

[73] Zubrin, Robert. 1999, *Entering Space - Creating a Spacefaring Civilization*

[74] (Joy 2000)

[75] (Acceleration Studies Foundation 2007)

[76] http://www.accelerationwatch.com/

[77] Dreyfus & Dreyfus 2000, p. xiv:

> "(...) The truth is that human intelligence can never be replaced with machine intelligence simply because we are not ourselves "thinking machines" in the sense in which that term is commonly understood.Hawking (1998) (...)"

:

> Some people say that computers can never show true intelligence whatever that may be. But it seems to me that if very complicated chemical molecules can operate in humans to make them intelligent then equally complicated electronic circuits can also make computers act in an intelligent way. And if they are intelligent they can presumably design computers that have even greater complexity and intelligence.

[78] Ford, Martin, *The Lights in the Tunnel: Automation, Accelerating Technology and the Economy of the Future* (http://www.thelightsinthetunnel.com), Acculant Publishing, 2009, ISBN 978-1-4486-5981-4

[79] Markoff, John (2011-03-04). "Armies of Expensive Lawyers, Replaced by Cheaper Software" (http://www.nytimes.com/2011/03/05/science/05legal.html). *The New York Times*. .

[80] Theodore Modis, Forecasting the Growth of Complexity and Change (http://www.google.com/search?q=cache:5qYje63ynXwJ:ourworld.compuserve.com/homepages/tmodis/TedWEB.htm+http://ourworld.compuserve.com/homepages/tmodis/TedWEB.htm&cd=1&hl=en&ct=clnk&gl=us), *Technological Forecasting & Social Change*, 69, No 4, 2002

[81] Modis, Theodore. *The Singularity Myth* (http://www.growth-dynamics.com/articles/Kurzweil.htm)

[82] Huebner, Jonathan (2005) A Possible Declining Trend for Worldwide Innovation, *Technological Forecasting & Social Change*, October 2005, pp. 980-6

[83] Smart, John (September 2005), On Huebner Innovation, Acceleration Studies Foundation, http://accelerating.org/articles/huebnerinnovation.html, retrieved on 2007-08-07

[84] Krazit, Tom. Intel pledges 80 cores in five years (http://news.cnet.com/2100-1006_3-6119618.html), *CNET News*, 26 September 2006.

[85] See, e.g., Korotayev A., Malkov A., Khaltourina D. *Introduction to Social Macrodynamics: Compact Macromodels of the World System Growth* (http://cliodynamics.ru/index.php?option=com_content&task=view&id=124&Itemid=70). Moscow: URSS Publishers, 2006; Korotayev A. V. A Compact Macromodel of World System Evolution // Journal of World-Systems Research 11/1 (2005): 79–93. (http://jwsr.ucr.edu/archive/vol11/number1/pdf/jwsr-v11n1-korotayev.pdf)

[86] For a detailed mathematical analysis of this issue see A Compact Mathematical Model of the World System Economic and Demographic Growth, 1 CE - 1973 CE (http://arxiv.org/abs/1206.0496).

[87] Interstellar Travel: The Wait Calculation and the Incentive Trap of Progress, JBIS Vol 59, N.7 July 2006

[88] Tainter, Joseph (1988) "The Collapse of Complex Societies" (Cambridge University Press)

[89] Myers, PZ, *Singularly Silly Singularity* (http://scienceblogs.com/pharyngula/2009/02/singularly_silly_singularity.php), , retrieved 2009-04-13

[90] Anonymous (18 March 2006), "More blades good" (http://www.economist.com/science/displaystory.cfm?story_id=5624861), *The Economist* (London) **378** (8469): 85,

[91] Plug & Pray (http://www.plugandpray-film.de/en/) Documentary film (2010) about the promise, problems and ethics of artificial intelligence and robotics

[92] Robo-scientist makes gene discovery-on its own | Crave - CNET (http://news.cnet.com/robo-scientist-makes-gene-discovery-on-its-own/?tag=newsLatestHeadlinesArea.0)

[93] Keim, Brandon (2009-04-02). "Computer Program Self-Discovers Laws of Physics" (http://www.wired.com/wiredscience/2009/04/newtonai/). *Wired*. .

[94] Cornell Chronicle: Computer derives natural laws (http://www.news.cornell.edu/stories/April09/NaturalLaws.ws.html)

[95] Michael Anissimov. "Interview with Dr. Steel" (http://ieet.org/index.php/IEET/more/2572/). Institute for Ethics and Emerging Technologies. . Retrieved 2009-08-29.

[96] Dr. Steel (Spring 2005). "Multi-Media Symbiosis and the Evolution of Electronic Life" (http://www.paranoiamagazine.com/backissues.html). Paranoia: The Conspiracy Reader, Issue 38 (back issue). . Retrieved 2010-04-16.

[97] Dr. Steel (Spring 2005). "Multi-Media Symbiosis and the Evolution of Electronic Life" (http://worlddominationtoys.com/drsteel/clippings_paranoia.html). *World Domination Toys* (clipping from Paranoia: The Conspiracy Reader). . Retrieved 2010-04-16.

[98] http://sola-mi.com

[99] http://imdb.com/title/tt2317127/

References

- Acceleration Studies Foundation (2007), *ASF: About the Foundation* (http://www.accelerating.org/about.html), retrieved 2007-11-13
- Anonymous (18 March 2006), "More blades good" (http://www.economist.com/science/displaystory.cfm?story_id=5624861), *The Economist* (London) **378** (8469): 85
- Bell, James John (2002), *Technotopia and the Death of Nature: Clones, Supercomputers, and Robots* (http://www.earthisland.org/journal/index.php/eij/article/technotopia_the_death_of_nature/), Earth Island Journal (first published in the November/December 2001 issue of the *Earth First! Journal*), retrieved 2007-08-07
- Bell, James John (1 May 2003), "Exploring The "Singularity"" (http://www.mindfully.org/Technology/2003/Singularity-Bell1may03.htm), *The Futurist* (World Future Society (mindfully.org)), retrieved 2007-08-07
- Berglas, Anthony (2008), *Artificial Intelligence will Kill our Grandchildren* (http://berglas.org/Articles/AIKillGrandchildren/AIKillGrandchildren.html), retrieved 2008-06-13
- Broderick, Damien (2001), *The Spike: How Our Lives Are Being Transformed by Rapidly Advancing Technologies*, New York: Forge, ISBN 0-312-87781-1

- Bostrom, Nick (2002), "Existential Risks" (http://www.nickbostrom.com/existential/risks.html), *Journal of Evolution and Technology* **9**, retrieved 2007-08-07
- Bostrom, Nick (2003), "Ethical Issues in Advanced Artificial Intelligence" (http://www.nickbostrom.com/ethics/ai.html), *Cognitive, Emotive and Ethical Aspects of Decision Making in Humans and in Artificial Intelligence* **2**: 12–17, retrieved 2007-08-07
- Dreyfus, Hubert L.; Dreyfus, Stuart E. (1 March 2000), *Mind over Machine: The Power of Human Intuition and Expertise in the Era of the Computer* (1 ed.), New York: Free Press, ISBN 0-7432-0551-0
- Ford, Martin (2009), *The Lights in the Tunnel: Automation, Accelerating Technology and the Economy of the Future* (http://www.thelightsinthetunnel.com), CreateSpace, ISBN 978-1-4486-5981-4.
- Good, I. J. (1965), Franz L. Alt and Morris Rubinoff, ed., "Speculations Concerning the First Ultraintelligent Machine" (http://web.archive.org/web/20010527181244/http://www.aeiveos.com/~bradbury/Authors/Computing/Good-IJ/SCtFUM.html), *Advances in Computers* (Academic Press) **6**: 31–88, archived from the original (http://www.aeiveos.com/~bradbury/Authors/Computing/Good-IJ/SCtFUM.html) on 2001-05-27, retrieved 2007-08-07
- Hanson, Robin (1998), *Some Skepticism* (http://hanson.gmu.edu/vc.html#hanson), Robin Hanson, retrieved 2009-06-19
- Hanson, Robin (June 2008), "Economics of the Singularity", *IEEE Spectrum*
- Hawking, Stephen (1998), *Science in the Next Millennium: Remarks by Stephen Hawking* (http://clinton2.nara.gov/Initiatives/Millennium/shawking.html), retrieved 2007-11-13
- Hawkins, Gerald S. (August 1983), *Mindsteps to the Cosmos*, HarperCollins, ISBN 0-06-015156-0
- Heylighen, Francis (2007), "Accelerating Socio-Technological Evolution: from ephemeralization and stigmergy to the global brain" (http://pespmc1.vub.ac.be/Papers/AcceleratingEvolution.pdf), in Modelski, G.; Devezas, T.; Thompson, W., *Globalization as an Evolutionary Process: Modeling Global Change*, London: Routledge, ISBN 978-0-415-77361-4
- Johansen, Anders; Sornette, Didier (25 January 2001), "Finite-time singularity in the dynamics of the world population, economic and financial indices" (http://hjem.get2net.dk/kgs/growthphysA.pdf) (PDF), *Physica A* **294** (3–4): 465–502, arXiv:cond-mat/0002075, Bibcode 2001PhyA..294..465J, doi:10.1016/S0378-4371(01)00105-4, retrieved 2007-10-30
- Joy, Bill (April 2000), "Why the future doesn't need us" (http://www.wired.com/wired/archive/8.04/joy.html), *Wired Magazine* (Viking Adult) (8.04), ISBN 0-670-03249-2, retrieved 2007-08-07
- Kurzweil, Raymond (2001), *The Law of Accelerating Returns* (http://lifeboat.com/ex/law.of.accelerating.returns), Lifeboat Foundation, retrieved 2007-08-07
- Kurzweil, Raymond (2005), *The Singularity Is Near*, New York: Viking, ISBN 0-670-03384-7
- Moravec, Hans (January 1992), "Pigs in Cyberspace" (http://www.frc.ri.cmu.edu/~hpm/project.archive/general.articles/1992/CyberPigs.html), *On the Cosmology and Ecology of Cyberspace*, retrieved 2007-11-21
- Schmidhuber, Jürgen (29 June 2006). "New Millennium AI and the Convergence of History". arXiv:cs/0606081 [cs.AI].
- Singularity Institute for Artificial Intelligence (2002), *Why Artificial Intelligence?* Archived (http://web.archive.org/20061004201151/www.singinst.org/intro/whyAI-print.html) October 4, 2006 at the Wayback Machine
- Singularity Institute for Artificial Intelligence (2004), *3 Laws Unsafe* (http://www.asimovlaws.com/), retrieved 2007-08-07
- Singularity Institute for Artificial Intelligence (2007), *What is the Singularity?* (http://www.singinst.org/overview/whatisthesingularity), retrieved 2008-01-04
- Smart, John (September 2005), *On Huebner Innovation* (http://accelerating.org/articles/huebnerinnovation.html), Acceleration Studies Foundation, retrieved 2007-08-07
- Ulam, Stanislaw (May 1958), "Tribute to John von Neumann", *Bulletin of the American Mathematical Society* **64** (nr 3, part 2): 1–49

- Vinge, Vernor (30–31 March 1993), "The Coming Technological Singularity" (http://www-rohan.sdsu.edu/faculty/vinge/misc/singularity.html), *Vision-21: Interdisciplinary Science & Engineering in the Era of CyberSpace, proceedings of a Symposium held at NASA Lewis Research Center* (NASA Conference Publication CP-10129), retrieved 2007-08-07. See also this HTML version (http://mindstalk.net/vinge/vinge-sing.html), retrieved on 2009-03-29.
- Warwick, Kevin (2004), *March of The Machines*, University of Illinois Press, ISBN 978-0-252-07223-9

External links

Non-fiction books

- Singularity Rising: Surviving and Thriving in a Smarter, Richer, and More Dangerous World (http://www.amazon.com/Singularity-Rising-Surviving-Thriving-Dangerous/dp/1936661659/ref=sr_1_1?s=books&ie=UTF8&qid=1336165392&sr=1-1) by James D. Miller, October 16, 2012.
- The Singularity Is Near: When Humans Transcend Biology (http://www.amazon.com/The-Singularity-Is-Near-Transcend/dp/0143037889/ref=tmm_pap_title_0) by Ray Kurzweil, September 26, 2006.
- The Spike: How Our Lives Are Being Transformed By Rapidly Advancing Technologies (http://www.amazon.com/Spike-Transformed-Rapidly-Advancing-Technologies/dp/031287782X/ref=sr_1_1?s=books&ie=UTF8&qid=1341175321&sr=1-1&keywords=the+spike) by Damien Broderick, February 9, 2002.

Essays and articles

- Singularities and Nightmares: Extremes of Optimism and Pessimism About the Human Future (http://lifeboat.com/ex/singularities.and.nightmares) by David Brin
- A Critical Discussion of Vinge’s Singularity Concept (http://hanson.gmu.edu/vi.html) by Robin Hanson
- Is a singularity just around the corner (http://hanson.gmu.edu/fastgrow.html) by Robin Hanson
- Brief History of Intellectual Discussion of Accelerating Change (http://www.accelerationwatch.com/history_brief.html) by John Smart
- One Half of a Manifesto (http://www.edge.org/documents/archive/edge74.html) by Jaron Lanier — a critique of "cybernetic totalism"
- One Half of an Argument (http://www.kurzweilai.net/meme/frame.html?main=/articles/art0236.html) — Ray Kurzweil's response to Lanier
- A discussion of Kurzweil, Turkel and Lanier (http://fortnightlyreview.co.uk/2010/08/the-wonders-of-man-in-the-age-of-simulations/) by Roger Berkowitz
- The Singularity Is Always Near (http://www.kk.org/thetechnium/archives/2006/02/the_singularity.php) by Kevin Kelly
- The Maes-Garreau Point (http://www.kk.org/thetechnium/archives/2007/03/the_maesgarreau.php) by Kevin Kelly
- "The Singularity - A Philosophical Analysis" (http://consc.net/papers/singularity.pdf) by David Chalmers
- 2045: The Year Man Becomes Immortal (http://www.time.com/time/health/article/0,8599,2048138,00.html), By Lev Grossman, time.com, Feb. 10, 2011.

Singularity AI projects

- The Singularity Institute for Artificial Intelligence (http://www.singinst.org/)
- The SSEC Machine Intelligence Project (http://www.ssec.wisc.edu/~billh/g/mi.html)
- The Artificial General Intelligence Research Institute (http://www.agiri.org/)

Fiction

- After Life (http://sifter.org/~simon/AfterLife/) by Simon Funk uses a complex narrative structure to explore the relationships among uploaded minds in a technological singularity.
- [Message Contains No Recognizable Symbols] (http://www.ssec.wisc.edu/~billh/g/mcnrs.html) by Bill Hibbard is a story about a technological singularity subject to the constraint that natural human authors are unable to depict the actions and dialog of super-intelligent minds.
- Much of Ben Goertzel's fiction (http://goertzel.org/fiction.htm) discusses a technological singularity.
- In "The Turk", an episode of the science fiction television series *Terminator: The Sarah Connor Chronicles*, John tells his mother about the singularity, a point in time when machines will be able to build superior versions of themselves without the aid of humans.
- *Accelerando* by Charles Stross
- *Dresden Codak*, a webcomic by Aaron Diaz, often contains plots relating to the singularity and transhumanism, especially in the *Hob* (http://www.dresdencodak.com/cartoons/dc_032.htm) story arc
- Endgame: Singularity is an open source game where the player is AI, whose goal is to attain technological singularity/apotheosis.

Other links

- Report on *The Stanford Singularity Summit* (http://www.jerrypournelle.com/reports/jerryp/singularity.html)
- 2007 quotes, Singularity Summit, San Francisco (http://www.singinst.org/summit2007/quotes/)
- Singularity Hub (http://singularityhub.com)
- An IEEE report on the Singularity. (http://www.spectrum.ieee.org/static/singularity)
- March 2007 Congressional Report on the Singularity (http://www.house.gov/jec/publications/110/nanotechnology_03-22-07.pdf) Alternate Link (http://www.thenewatlantis.com/docLib/20120213_TheFutureisComingSoonerThanYouThink.pdf)
- The Global Transition (http://www.theglobaltransition.com)

Artificial intelligence

Artificial intelligence (**AI**) is the intelligence of machines and the branch of computer science that aims to create it. AI textbooks define the field as "the study and design of intelligent agents"[1] where an intelligent agent is a system that perceives its environment and takes actions that maximize its chances of success.[2] John McCarthy, who coined the term in 1955,[3] defines it as "the science and engineering of making intelligent machines."[4]

AI research is highly technical and specialized, deeply divided into subfields that often fail to communicate with each other.[5] Some of the division is due to social and cultural factors: subfields have grown up around particular institutions and the work of individual researchers. AI research is also divided by several technical issues. There are subfields which are focused on the solution of specific problems, on one of several possible approaches, on the use of widely differing tools and towards the accomplishment of particular applications. The central problems of AI include such traits as reasoning, knowledge, planning, learning, communication, perception and the ability to move and manipulate objects.[6] General intelligence (or "strong AI") is still among the field's long term goals.[7] Currently popular approaches include statistical methods, computational intelligence and traditional symbolic AI. There are an enormous number of tools used in AI, including versions of search and mathematical optimization, logic, methods based on probability and economics, and many others.

The field was founded on the claim that a central property of humans, intelligence—the sapience of *Homo sapiens*—can be so precisely described that it can be simulated by a machine.[8] This raises philosophical issues about the nature of the mind and the ethics of creating artificial beings, issues which have been addressed by myth, fiction and philosophy since antiquity.[9] Artificial intelligence has been the subject of optimism,[10] but has also suffered setbacks[11] and, today, has become an essential part of the technology industry, providing the heavy lifting for many of the most difficult problems in computer science.[12]

History

Thinking machines and artificial beings appear in Greek myths, such as Talos of Crete, the bronze robot of Hephaestus, and Pygmalion's Galatea.[13] Human likenesses believed to have intelligence were built in every major civilization: animated cult images were worshipped in Egypt and Greece[14] and humanoid automatons were built by Yan Shi, Hero of Alexandria and Al-Jazari.[15] It was also widely believed that artificial beings had been created by Jābir ibn Hayyān, Judah Loew and Paracelsus.[16] By the 19th and 20th centuries, artificial beings had become a common feature in fiction, as in Mary Shelley's *Frankenstein* or Karel Čapek's *R.U.R. (Rossum's Universal Robots)*.[17] Pamela McCorduck argues that all of these are examples of an ancient urge, as she describes it, "to forge the gods".[9] Stories of these creatures and their fates discuss many of the same hopes, fears and ethical concerns that are presented by artificial intelligence.

Mechanical or "formal" reasoning has been developed by philosophers and mathematicians since antiquity. The study of logic led directly to the invention of the programmable digital electronic computer, based on the work of mathematician Alan Turing and others. Turing's theory of computation suggested that a machine, by shuffling symbols as simple as "0" and "1", could simulate any conceivable (imaginable) act of mathematical deduction.[18][19] This, along with concurrent discoveries in neurology, information theory and cybernetics, inspired a small group of researchers to begin to seriously consider the possibility of building an electronic brain.[20]

The field of AI research was founded at a conference on the campus of Dartmouth College in the summer of 1956.[21] The attendees, including John McCarthy, Marvin Minsky, Allen Newell and Herbert Simon, became the leaders of AI research for many decades.[22] They and their students wrote programs that were, to most people, simply astonishing:[23] Computers were solving word problems in algebra, proving logical theorems and speaking English.[24] By the middle of the 1960s, research in the U.S. was heavily funded by the Department of Defense[25] and laboratories had been established around the world.[26] AI's founders were profoundly optimistic about the future

of the new field: Herbert Simon predicted that "machines will be capable, within twenty years, of doing any work a man can do" and Marvin Minsky agreed, writing that "within a generation ... the problem of creating 'artificial intelligence' will substantially be solved".[27]

They had failed to recognize the difficulty of some of the problems they faced.[28] In 1974, in response to the criticism of Sir James Lighthill and ongoing pressure from the US Congress to fund more productive projects, both the U.S. and British governments cut off all undirected exploratory research in AI. The next few years, when funding for projects was hard to find, would later be called the "AI winter".[29]

In the early 1980s, AI research was revived by the commercial success of expert systems,[30] a form of AI program that simulated the knowledge and analytical skills of one or more human experts. By 1985 the market for AI had reached over a billion dollars. At the same time, Japan's fifth generation computer project inspired the U.S and British governments to restore funding for academic research in the field.[31] However, beginning with the collapse of the Lisp Machine market in 1987, AI once again fell into disrepute, and a second, longer lasting AI winter began.[32]

In the 1990s and early 21st century, AI achieved its greatest successes, albeit somewhat behind the scenes. Artificial intelligence is used for logistics, data mining, medical diagnosis and many other areas throughout the technology industry.[12] The success was due to several factors: the increasing computational power of computers (see Moore's law), a greater emphasis on solving specific subproblems, the creation of new ties between AI and other fields working on similar problems, and a new commitment by researchers to solid mathematical methods and rigorous scientific standards.[33]

On 11 May 1997, Deep Blue became the first computer chess-playing system to beat a reigning world chess champion, Garry Kasparov.[34] In 2005, a Stanford robot won the DARPA Grand Challenge by driving autonomously for 131 miles along an unrehearsed desert trail.[35] Two years later, a team from CMU won the DARPA Urban Challenge when their vehicle autonomously navigated 55 miles in an Urban environment while adhering to traffic hazards and all traffic laws.[36] In February 2011, in a Jeopardy! quiz show exhibition match, IBM's question answering system, Watson, defeated the two greatest Jeopardy! champions, Brad Rutter and Ken Jennings, by a significant margin.[37]

The leading-edge definition of artificial intelligence research is changing over time. One pragmatic definition is: "AI research is that which computing scientists do not know how to do cost-effectively today." For example, in 1956 optical character recognition (OCR) was considered AI, but today, sophisticated OCR software with a context-sensitive spell checker and grammar checker software comes for free with most image scanners. No one would any longer consider already-solved computing science problems like OCR "artificial intelligence" today.

Low-cost entertaining chess-playing software is commonly available for tablet computers. DARPA no longer provides significant funding for chess-playing computing system development. The Kinect which provides a 3D body–motion interface for the Xbox 360 uses algorithms that emerged from lengthy AI research,[38] but few consumers realize the technology source.

AI applications are no longer the exclusive domain of U.S. Department of Defense R&D, but are now commonplace consumer items and inexpensive intelligent toys.

In common usage, the term "AI" no longer seems to apply to off-the-shelf solved computing-science problems, which may have originally emerged out of years of AI research.

Problems

The general problem of simulating (or creating) intelligence has been broken down into a number of specific sub-problems. These consist of particular traits or capabilities that researchers would like an intelligent system to display. The traits described below have received the most attention.[6]

Deduction, reasoning, problem solving

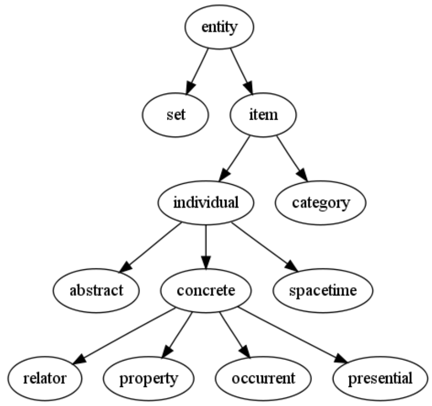
Early AI researchers developed algorithms that imitated the step-by-step reasoning that humans use when they solve puzzles or make logical deductions.[39] By the late 1980s and '90s, AI research had also developed highly successful methods for dealing with uncertain or incomplete information, employing concepts from probability and economics.[40]

For difficult problems, most of these algorithms can require enormous computational resources – most experience a "combinatorial explosion": the amount of memory or computer time required becomes astronomical when the problem goes beyond a certain size. The search for more efficient problem-solving algorithms is a high priority for AI research.[41]

Human beings solve most of their problems using fast, intuitive judgements rather than the conscious, step-by-step deduction that early AI research was able to model.[42] AI has made some progress at imitating this kind of "sub-symbolic" problem solving: embodied agent approaches emphasize the importance of sensorimotor skills to higher reasoning; neural net research attempts to simulate the structures inside the brain that give rise to this skill; statistical approaches to AI mimic the probabilistic nature of the human ability to guess.

Knowledge representation

Knowledge representation[43] and knowledge engineering[44] are central to AI research. Many of the problems machines are expected to solve will require extensive knowledge about the world. Among the things that AI needs to represent are: objects, properties, categories and relations between objects;[45] situations, events, states and time;[46] causes and effects;[47] knowledge about knowledge (what we know about what other people know);[48] and many other, less well researched domains. A representation of "what exists" is an ontology (borrowing a word from traditional philosophy), of which the most general are called upper ontologies.[49]



An ontology represents knowledge as a set of concepts within a domain and the relationships between those concepts.

Among the most difficult problems in knowledge representation are:

Default reasoning and the qualification problem

Many of the things people know take the form of "working assumptions." For example, if a bird comes up in conversation, people typically picture an animal that is fist sized, sings, and flies. None of these things are true about all birds. John McCarthy identified this problem in 1969[50] as the qualification problem: for any commonsense rule that AI researchers care to represent, there tend to be a huge number of exceptions. Almost nothing is simply true or false in the way that abstract logic requires. AI research has explored a number of solutions to this problem.[51]

The breadth of commonsense knowledge

The number of atomic facts that the average person knows is astronomical. Research projects that attempt to build a complete knowledge base of commonsense knowledge (e.g., Cyc) require enormous amounts of laborious ontological engineering — they must be built, by hand, one complicated concept at a time.[52] A

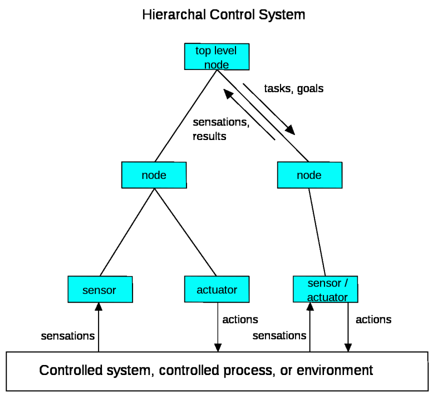
major goal is to have the computer understand enough concepts to be able to learn by reading from sources like the internet, and thus be able to add to its own ontology.

The subsymbolic form of some commonsense knowledge

Much of what people know is not represented as "facts" or "statements" that they could express verbally. For example, a chess master will avoid a particular chess position because it "feels too exposed"[53] or an art critic can take one look at a statue and instantly realize that it is a fake.[54] These are intuitions or tendencies that are represented in the brain non-consciously and sub-symbolically.[55] Knowledge like this informs, supports and provides a context for symbolic, conscious knowledge. As with the related problem of sub-symbolic reasoning, it is hoped that situated AI, computational intelligence, or statistical AI will provide ways to represent this kind of knowledge.[55]

Planning

Intelligent agents must be able to set goals and achieve them.[56] They need a way to visualize the future (they must have a representation of the state of the world and be able to make predictions about how their actions will change it) and be able to make choices that maximize the utility (or "value") of the available choices.[57]



A hierarchical control system is a form of control system in which a set of devices and governing software is arranged in a hierarchy.

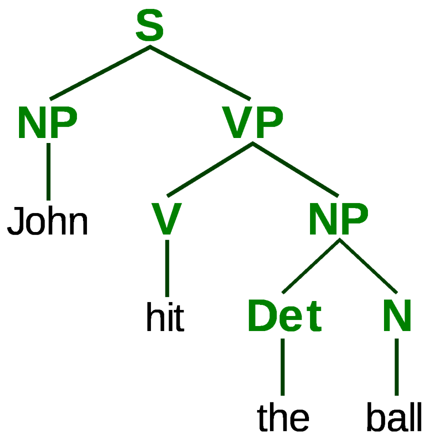
In classical planning problems, the agent can assume that it is the only thing acting on the world and it can be certain what the consequences of its actions may be.[58] However, if the agent is not the only actor, it must periodically ascertain whether the world matches its predictions and it must change its plan as this becomes necessary, requiring the agent to reason under uncertainty.[59]

Multi-agent planning uses the cooperation and competition of many agents to achieve a given goal. Emergent behavior such as this is used by evolutionary algorithms and swarm intelligence.[60]

Learning

Machine learning[61] has been central to AI research from the beginning.[62] In 1956, at the original Dartmouth AI summer conference, Ray Solomonoff wrote a report on unsupervised probabilistic machine learning: "An Inductive Inference Machine".[63] Unsupervised learning is the ability to find patterns in a stream of input. Supervised learning includes both classification and numerical regression. Classification is used to determine what category something belongs in, after seeing a number of examples of things from several categories. Regression is the attempt to produce a function that describes the relationship between inputs and outputs and predicts how the outputs should change as the inputs change. In reinforcement learning[64] the agent is rewarded for good responses and punished for bad ones. These can be analyzed in terms of decision theory, using concepts like utility. The mathematical analysis of machine learning algorithms and their performance is a branch of theoretical computer science known as computational learning theory.[65]

Natural language processing



A parse tree represents the syntactic structure of a sentence according to some formal grammar.

Natural language processing[66] gives machines the ability to read and understand the languages that humans speak. A sufficiently powerful natural language processing system would enable natural language user interfaces and the acquisition of knowledge directly from human-written sources, such as Internet texts. Some straightforward applications of natural language processing include information retrieval (or text mining) and machine translation.[67]

A common method of processing and extracting meaning from natural language is through semantic indexing. Increases in processing speeds and the drop in the cost of data storage makes indexing large volumes of abstractions of the users input much more efficient.

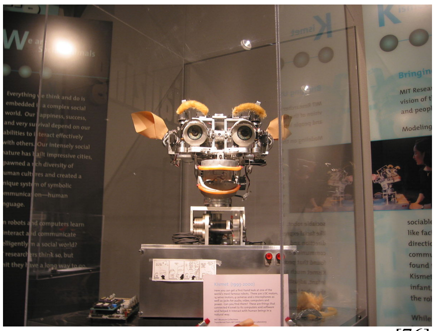
Motion and manipulation

The field of robotics[68] is closely related to AI. Intelligence is required for robots to be able to handle such tasks as object manipulation[69] and navigation, with sub-problems of localization (knowing where you are, or finding out where other things are), mapping (learning what is around you, building a map of the environment), and motion planning (figuring out how to get there) or path planning (going from one point in space to another point, which may involve compliant motion - where the robot moves while maintaining physical contact with an object).[70][71]

Perception

Machine perception[72] is the ability to use input from sensors (such as cameras, microphones, sonar and others more exotic) to deduce aspects of the world. Computer vision[73] is the ability to analyze visual input. A few selected subproblems are speech recognition,[74] facial recognition and object recognition.[75]

Social intelligence


Kismet, a robot with rudimentary social skills[76]

Affective computing is the study and development of systems and devices that can recognize, interpret, process, and simulate human affects.[77][78] It is an interdisciplinary field spanning computer sciences, psychology, and cognitive science.[79] While the origins of the field may be traced as far back as to early philosophical enquiries into emotion,[80] the more modern branch of computer science originated with Rosalind Picard's 1995 paper[81] on affective computing.[82][83] A motivation for the research is the ability to simulate empathy. The machine should interpret the emotional state of humans and adapt its behaviour to them, giving an appropriate response for those emotions.

Emotion and social skills[84] play two roles for an intelligent agent. First, it must be able to predict the actions of others, by understanding their motives and emotional states. (This involves elements of game theory, decision theory, as well as the ability to model human emotions and the perceptual skills to detect emotions.) Also, in an effort to facilitate human-computer interaction, an intelligent machine might want to be able to *display* emotions—even if it does not actually experience them itself—in order to appear sensitive to the emotional dynamics of human interaction.

Creativity

A sub-field of AI addresses creativity both theoretically (from a philosophical and psychological perspective) and practically (via specific implementations of systems that generate outputs that can be considered creative, or systems that identify and assess creativity). Related areas of computational research are Artificial intuition and Artificial imagination.

General intelligence

Most researchers hope that their work will eventually be incorporated into a machine with *general* intelligence (known as strong AI), combining all the skills above and exceeding human abilities at most or all of them.[7] A few believe that anthropomorphic features like artificial consciousness or an artificial brain may be required for such a project.[85][86]

Many of the problems above are considered AI-complete: to solve one problem, you must solve them all. For example, even a straightforward, specific task like machine translation requires that the machine follow the author's argument (reason), know what is being talked about (knowledge), and faithfully reproduce the author's intention (social intelligence). Machine translation, therefore, is believed to be AI-complete: it may require strong AI to be done as well as humans can do it.[87]

Approaches

There is no established unifying theory or paradigm that guides AI research. Researchers disagree about many issues.[88] A few of the most long standing questions that have remained unanswered are these: should artificial intelligence simulate natural intelligence by studying psychology or neurology? Or is human biology as irrelevant to AI research as bird biology is to aeronautical engineering?[89] Can intelligent behavior be described using simple, elegant principles (such as logic or optimization)? Or does it necessarily require solving a large number of completely unrelated problems?[90] Can intelligence be reproduced using high-level symbols, similar to words and ideas? Or does it require "sub-symbolic" processing?[91] John Haugeland, who coined the term GOFAI (Good Old-Fashioned Artificial Intelligence), also proposed that AI should more properly be referred to as synthetic intelligence,[92] a term which has since been adopted by some non-GOFAI researchers.[93][94]

Cybernetics and brain simulation

In the 1940s and 1950s, a number of researchers explored the connection between neurology, information theory, and cybernetics. Some of them built machines that used electronic networks to exhibit rudimentary intelligence, such as W. Grey Walter's turtles and the Johns Hopkins Beast. Many of these researchers gathered for meetings of the Teleological Society at Princeton University and the Ratio Club in England.[20] By 1960, this approach was largely abandoned, although elements of it would be revived in the 1980s.

Symbolic

When access to digital computers became possible in the middle 1950s, AI research began to explore the possibility that human intelligence could be reduced to symbol manipulation. The research was centered in three institutions: CMU, Stanford and MIT, and each one developed its own style of research. John Haugeland named these approaches to AI "good old fashioned AI" or "GOFAI".[95] During the 1960s, symbolic approaches had achieved great success at simulating high-level thinking in small demonstration programs. Approaches based on cybernetics or neural networks were abandoned or pushed into the background.[96] Researchers in the 1960s and the 1970s were convinced that symbolic approaches would eventually succeed in creating a machine with artificial general intelligence and considered this the goal of their field.

Cognitive simulation

Economist Herbert Simon and Allen Newell studied human problem-solving skills and attempted to formalize them, and their work laid the foundations of the field of artificial intelligence, as well as cognitive science, operations research and management science. Their research team used the results of psychological experiments to develop programs that simulated the techniques that people used to solve problems. This tradition, centered at Carnegie Mellon University would eventually culminate in the development of the Soar architecture in the middle 80s.[97][98]

Logic-based

Unlike Newell and Simon, John McCarthy felt that machines did not need to simulate human thought, but should instead try to find the essence of abstract reasoning and problem solving, regardless of whether people used the same algorithms.[89] His laboratory at Stanford (SAIL) focused on using formal logic to solve a wide variety of problems, including knowledge representation, planning and learning.[99] Logic was also focus of the work at the University of Edinburgh and elsewhere in Europe which led to the development of the programming language Prolog and the science of logic programming.[100]

"Anti-logic" or "scruffy"

Researchers at MIT (such as Marvin Minsky and Seymour Papert)[101] found that solving difficult problems in vision and natural language processing required ad-hoc solutions – they argued that there was no simple and general principle (like logic) that would capture all the aspects of intelligent behavior. Roger Schank described their "anti-logic" approaches as "scruffy" (as opposed to the "neat" paradigms at CMU and Stanford).[90] Commonsense knowledge bases (such as Doug Lenat's Cyc) are an example of "scruffy" AI, since they must be built by hand, one complicated concept at a time.[102]

Knowledge-based

When computers with large memories became available around 1970, researchers from all three traditions began to build knowledge into AI applications.[103] This "knowledge revolution" led to the development and deployment of expert systems (introduced by Edward Feigenbaum), the first truly successful form of AI software.[30] The knowledge revolution was also driven by the realization that enormous amounts of knowledge would be required by many simple AI applications.

Sub-symbolic

By the 1980s progress in symbolic AI seemed to stall and many believed that symbolic systems would never be able to imitate all the processes of human cognition, especially perception, robotics, learning and pattern recognition. A number of researchers began to look into "sub-symbolic" approaches to specific AI problems.[91]

Bottom-up, embodied, situated, behavior-based or nouvelle AI

Researchers from the related field of robotics, such as Rodney Brooks, rejected symbolic AI and focused on the basic engineering problems that would allow robots to move and survive.[104] Their work revived the non-symbolic viewpoint of the early cybernetics researchers of the 50s and reintroduced the use of control theory in AI. This coincided with the development of the embodied mind thesis in the related field of cognitive science: the idea that aspects of the body (such as movement, perception and visualization) are required for higher intelligence.

Computational Intelligence

Interest in neural networks and "connectionism" was revived by David Rumelhart and others in the middle 1980s.[105] These and other sub-symbolic approaches, such as fuzzy systems and evolutionary computation, are now studied collectively by the emerging discipline of computational intelligence.[106]

Statistical

In the 1990s, AI researchers developed sophisticated mathematical tools to solve specific subproblems. These tools are truly scientific, in the sense that their results are both measurable and verifiable, and they have been responsible for many of AI's recent successes. The shared mathematical language has also permitted a high level of collaboration with more established fields (like mathematics, economics or operations research). Stuart Russell and Peter Norvig describe this movement as nothing less than a "revolution" and "the victory of the neats."[33] Critics argue that these techniques are too focused on particular problems and have failed to address the long term goal of general intelligence.[107]

Integrating the approaches

Intelligent agent paradigm

An intelligent agent is a system that perceives its environment and takes actions which maximize its chances of success. The simplest intelligent agents are programs that solve specific problems. More complicated agents include human beings and organizations of human beings (such as firms). The paradigm gives researchers license to study isolated problems and find solutions that are both verifiable and useful, without agreeing on one single approach. An agent that solves a specific problem can use any approach that works – some agents are symbolic and logical, some are sub-symbolic neural networks and others may use new approaches. The paradigm also gives researchers a common language to communicate with other fields—such as decision theory and economics—that also use concepts of abstract agents. The intelligent agent paradigm became widely accepted during the 1990s.[2]

Agent architectures and cognitive architectures

Researchers have designed systems to build intelligent systems out of interacting intelligent agents in a multi-agent system.[108] A system with both symbolic and sub-symbolic components is a hybrid intelligent system, and the study of such systems is artificial intelligence systems integration. A hierarchical control system provides a bridge between sub-symbolic AI at its lowest, reactive levels and traditional symbolic AI at its highest levels, where relaxed time constraints permit planning and world modelling.[109] Rodney Brooks' subsumption architecture was an early proposal for such a hierarchical system.[110]

Tools

In the course of 50 years of research, AI has developed a large number of tools to solve the most difficult problems in computer science. A few of the most general of these methods are discussed below.

Search and optimization

Many problems in AI can be solved in theory by intelligently searching through many possible solutions:[111] Reasoning can be reduced to performing a search. For example, logical proof can be viewed as searching for a path that leads from premises to conclusions, where each step is the application of an inference rule.[112] Planning algorithms search through trees of goals and subgoals, attempting to find a path to a target goal, a process called means-ends analysis.[113] Robotics algorithms for moving limbs and grasping objects use local searches in configuration space.[69] Many learning algorithms use search algorithms based on optimization.

Simple exhaustive searches[114] are rarely sufficient for most real world problems: the search space (the number of places to search) quickly grows to astronomical numbers. The result is a search that is too slow or never completes. The solution, for many problems, is to use "heuristics" or "rules of thumb" that eliminate choices that are unlikely to lead to the goal (called "pruning the search tree"). Heuristics supply the program with a "best guess" for the path on which the solution lies.[115]

A very different kind of search came to prominence in the 1990s, based on the mathematical theory of optimization. For many problems, it is possible to begin the search with some form of a guess and then refine the guess incrementally until no more refinements can be made. These algorithms can be visualized as blind hill climbing: we begin the search at a random point on the landscape, and then, by jumps or steps, we keep moving our guess uphill, until we reach the top. Other optimization algorithms are simulated annealing, beam search and random optimization.[116]

Evolutionary computation uses a form of optimization search. For example, they may begin with a population of organisms (the guesses) and then allow them to mutate and recombine, selecting only the fittest to survive each generation (refining the guesses). Forms of evolutionary computation include swarm intelligence algorithms (such as ant colony or particle swarm optimization)[117] and evolutionary algorithms (such as genetic algorithms, gene expression programming, and genetic programming).[118]

Logic

Logic[119] is used for knowledge representation and problem solving, but it can be applied to other problems as well. For example, the satplan algorithm uses logic for planning[120] and inductive logic programming is a method for learning.[121]

Several different forms of logic are used in AI research. Propositional or sentential logic[122] is the logic of statements which can be true or false. First-order logic[123] also allows the use of quantifiers and predicates, and can express facts about objects, their properties, and their relations with each other. Fuzzy logic,[124] is a version of first-order logic which allows the truth of a statement to be represented as a value between 0 and 1, rather than simply True (1) or False (0). Fuzzy systems can be used for uncertain reasoning and have been widely used in modern industrial and consumer product control systems. Subjective logic[125] models uncertainty in a different and more explicit manner than fuzzy-logic: a given binomial opinion satisfies belief + disbelief + uncertainty = 1 within a Beta distribution. By this method, ignorance can be distinguished from probabilistic statements that an agent makes with high confidence.

Default logics, non-monotonic logics and circumscription[51] are forms of logic designed to help with default reasoning and the qualification problem. Several extensions of logic have been designed to handle specific domains of knowledge, such as: description logics;[45] situation calculus, event calculus and fluent calculus (for representing events and time);[46] causal calculus;[47] belief calculus; and modal logics.[48]

Probabilistic methods for uncertain reasoning

Many problems in AI (in reasoning, planning, learning, perception and robotics) require the agent to operate with incomplete or uncertain information. AI researchers have devised a number of powerful tools to solve these problems using methods from probability theory and economics.[126]

Bayesian networks[127] are a very general tool that can be used for a large number of problems: reasoning (using the Bayesian inference algorithm),[128] learning (using the expectation-maximization algorithm),[129] planning (using decision networks)[130] and perception (using dynamic Bayesian networks).[131] Probabilistic algorithms can also be used for filtering, prediction, smoothing and finding explanations for streams of data, helping perception systems to analyze processes that occur over time (e.g., hidden Markov models or Kalman filters).[131]

A key concept from the science of economics is "utility": a measure of how valuable something is to an intelligent agent. Precise mathematical tools have been developed that analyze how an agent can make choices and plan, using decision theory, decision analysis,[132] information value theory.[57] These tools include models such as Markov decision processes,[133] dynamic decision networks,[131] game theory and mechanism design.[134]

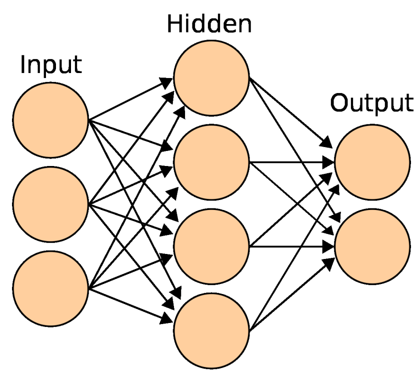
Classifiers and statistical learning methods

The simplest AI applications can be divided into two types: classifiers ("if shiny then diamond") and controllers ("if shiny then pick up"). Controllers do however also classify conditions before inferring actions, and therefore classification forms a central part of many AI systems. Classifiers are functions that use pattern matching to determine a closest match. They can be tuned according to examples, making them very attractive for use in AI. These examples are known as observations or patterns. In supervised learning, each pattern belongs to a certain predefined class. A class can be seen as a decision that has to be made. All the observations combined with their class labels are known as a data set. When a new observation is received, that observation is classified based on previous experience.[135]

A classifier can be trained in various ways; there are many statistical and machine learning approaches. The most widely used classifiers are the neural network,[136] kernel methods such as the support vector machine,[137] k-nearest neighbor algorithm,[138] Gaussian mixture model,[139] naive Bayes classifier,[140] and decision tree.[141] The performance of these classifiers have been compared over a wide range of tasks. Classifier performance depends greatly on the characteristics of the data to be classified. There is no single classifier that works best on all given problems; this is also referred to as the "no free lunch" theorem. Determining a suitable classifier for a given problem is still more an art than science.[142]

Neural networks

The study of artificial neural networks[136] began in the decade before the field AI research was founded, in the work of Walter Pitts and Warren McCullough. Other important early researchers were Frank Rosenblatt, who invented the perceptron and Paul Werbos who developed the backpropagation algorithm.[143]



A neural network is an interconnected group of nodes, akin to the vast network of neurons in the human brain.

The main categories of networks are acyclic or feedforward neural networks (where the signal passes in only one direction) and recurrent neural networks (which allow feedback). Among the most popular feedforward networks are perceptrons, multi-layer perceptrons and radial basis networks.[144] Among recurrent networks, the most famous is the Hopfield net, a form of attractor network, which was first described by John Hopfield in 1982.[145] Neural networks can be applied to the problem of intelligent control (for robotics) or learning, using such techniques as Hebbian learning and competitive learning.[146]

Hierarchical temporal memory is an approach that models some of the structural and algorithmic properties of the neocortex.[147]

Control theory

Control theory, the grandchild of cybernetics, has many important applications, especially in robotics.[148]

Languages

AI researchers have developed several specialized languages for AI research, including Lisp[149] and Prolog.[150]

Evaluating progress

In 1950, Alan Turing proposed a general procedure to test the intelligence of an agent now known as the Turing test. This procedure allows almost all the major problems of artificial intelligence to be tested. However, it is a very difficult challenge and at present all agents fail.[151]

Artificial intelligence can also be evaluated on specific problems such as small problems in chemistry, hand-writing recognition and game-playing. Such tests have been termed subject matter expert Turing tests. Smaller problems provide more achievable goals and there are an ever-increasing number of positive results.[152]

One classification for outcomes of an AI test is:[153]

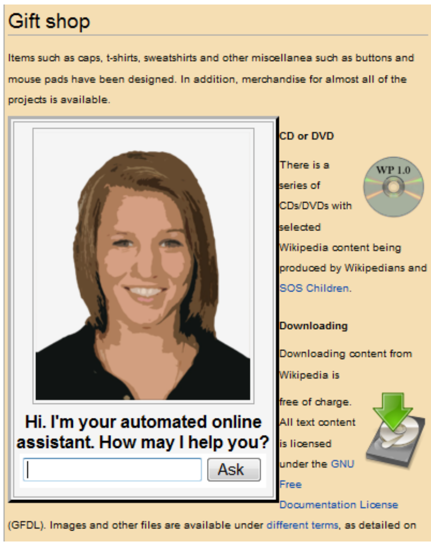
1. Optimal: it is not possible to perform better.
2. Strong super-human: performs better than all humans.
3. Super-human: performs better than most humans.
4. Sub-human: performs worse than most humans.

For example, performance at draughts is optimal,[154] performance at chess is super-human and nearing strong super-human (see computer chess: computers versus human) and performance at many everyday tasks (such as recognizing a face or crossing a room without bumping into something) is sub-human.

A quite different approach measures machine intelligence through tests which are developed from *mathematical* definitions of intelligence. Examples of these kinds of tests start in the late nineties devising intelligence tests using notions from Kolmogorov complexity and data compression.[155] Two major advantages of mathematical definitions are their applicability to nonhuman intelligences and their absence of a requirement for human testers.

Applications

Artificial intelligence techniques are pervasive and are too numerous to list. Frequently, when a technique reaches mainstream use, it is no longer considered artificial intelligence; this phenomenon is described as the AI effect.[156]



An automated online assistant providing customer service on a web page – one of many very primitive applications of artificial intelligence.

Competitions and prizes

There are a number of competitions and prizes to promote research in artificial intelligence. The main areas promoted are: general machine intelligence, conversational behavior, data-mining, driverless cars, robot soccer and games.

Platforms

A platform (or "computing platform") is defined as "some sort of hardware architecture or software framework (including application frameworks), that allows software to run." As Rodney Brooks[157] pointed out many years ago, it is not just the artificial intelligence software that defines the AI features of the platform, but rather the actual platform itself that affects the AI that results, i.e., there needs to be work in AI problems on real-world platforms rather than in isolation.

A wide variety of platforms has allowed different aspects of AI to develop, ranging from expert systems, albeit PC-based but still an entire real-world system, to various robot platforms such as the widely available Roomba with open interface.[158]

Philosophy

Artificial intelligence, by claiming to be able to recreate the capabilities of the human mind, is both a challenge and an inspiration for philosophy. Are there limits to how intelligent machines can be? Is there an essential difference between human intelligence and artificial intelligence? Can a machine have a mind and consciousness? A few of the most influential answers to these questions are given below.[159]

Turing's "polite convention": We need not decide if a machine can "think"; we need only decide if a machine can act as intelligently as a human being. This approach to the philosophical problems associated with artificial intelligence forms the basis of the Turing test.[151]

The Dartmouth proposal: "Every aspect of learning or any other feature of intelligence can be so precisely described that a machine can be made to simulate it." This conjecture was printed in the proposal for the Dartmouth Conference of 1956, and represents the position of most working AI researchers.[160]

Newell and Simon's physical symbol system hypothesis: "A physical symbol system has the necessary and sufficient means of general intelligent action." Newell and Simon argue that intelligences consist of formal operations on symbols.[161] Hubert Dreyfus argued that, on the contrary, human expertise depends on unconscious instinct rather than conscious symbol manipulation and on having a "feel" for the situation rather than explicit symbolic knowledge. (See Dreyfus' critique of AI.)[162][163]

Gödel's incompleteness theorem: A formal system (such as a computer program) cannot prove all true statements.[164] Roger Penrose is among those who claim that Gödel's theorem limits what machines can do. (See *The Emperor's New Mind*.)[165]

Searle's strong AI hypothesis: "The appropriately programmed computer with the right inputs and outputs would thereby have a mind in exactly the same sense human beings have minds."[166] John Searle counters this assertion with his Chinese room argument, which asks us to look *inside* the computer and try to find where the "mind" might be.[167]

The artificial brain argument: The brain can be simulated. Hans Moravec, Ray Kurzweil and others have argued that it is technologically feasible to copy the brain directly into hardware and software, and that such a simulation will be essentially identical to the original.[86]

Predictions and ethics

Artificial Intelligence is a common topic in both science fiction and projections about the future of technology and society. The existence of an artificial intelligence that rivals human intelligence raises difficult ethical issues, and the potential power of the technology inspires both hopes and fears.

In fiction, Artificial Intelligence has appeared fulfilling many roles, including a servant (R2D2 in *Star Wars*), a law enforcer (K.I.T.T. "Knight Rider"), a comrade (Lt. Commander Data in *Star Trek: The Next Generation*), a conqueror/overlord (*The Matrix*), a dictator (*With Folded Hands*), a benevolent provider/de facto ruler (*The Culture*), an assassin (*Terminator*), a sentient race (*Battlestar Galactica*/Transformers/*Mass Effect*), an extension to human abilities (*Ghost in the Shell*) and the savior of the human race (R. Daneel Olivaw in Isaac Asimov's *Robot* series).

Mary Shelley's *Frankenstein* considers a key issue in the ethics of artificial intelligence: if a machine can be created that has intelligence, could it also *feel*? If it can feel, does it have the same rights as a human? The idea also appears in modern science fiction, including the films *I Robot*, *Blade Runner* and *A.I.: Artificial Intelligence*, in which humanoid machines have the ability to feel human emotions. This issue, now known as "robot rights", is currently being considered by, for example, California's Institute for the Future, although many critics believe that the discussion is premature.[168] The subject is profoundly discussed in the 2010 documentary film *Plug & Pray*.[169]

Martin Ford, author of *The Lights in the Tunnel: Automation, Accelerating Technology and the Economy of the Future*,[170] and others argue that specialized artificial intelligence applications, robotics and other forms of automation will ultimately result in significant unemployment as machines begin to match and exceed the capability of workers to perform most routine and repetitive jobs. Ford predicts that many knowledge-based occupations—and in particular entry level jobs—will be increasingly susceptible to automation via expert systems, machine learning[171] and other AI-enhanced applications. AI-based applications may also be used to amplify the capabilities of low-wage offshore workers, making it more feasible to outsource knowledge work.[172]

Joseph Weizenbaum wrote that AI applications can not, by definition, successfully simulate genuine human empathy and that the use of AI technology in fields such as customer service or psychotherapy[173] was deeply misguided. Weizenbaum was also bothered that AI researchers (and some philosophers) were willing to view the human mind as nothing more than a computer program (a position now known as computationalism). To Weizenbaum these points suggest that AI research devalues human life.[174]

Many futurists believe that artificial intelligence will ultimately transcend the limits of progress. Ray Kurzweil has used Moore's law (which describes the relentless exponential improvement in digital technology) to calculate that desktop computers will have the same processing power as human brains by the year 2029. He also predicts that by 2045 artificial intelligence will reach a point where it is able to improve *itself* at a rate that far exceeds anything conceivable in the past, a scenario that science fiction writer Vernor Vinge named the "singularity".[175]

Robot designer Hans Moravec, cyberneticist Kevin Warwick and inventor Ray Kurzweil have predicted that humans and machines will merge in the future into cyborgs that are more capable and powerful than either.[176] This idea, called transhumanism, which has roots in Aldous Huxley and Robert Ettinger, has been illustrated in fiction as well, for example in the manga *Ghost in the Shell* and the science-fiction series *Dune*.

Political scientist Charles T. Rubin believes that AI can be neither designed nor guaranteed to be friendly.[177] He argues that "any sufficiently advanced benevolence may be indistinguishable from malevolence." Humans should not assume machines or robots would treat us favorably, because there is no *a priori* reason to believe that they would be sympathetic to our system of morality, which has evolved along with our particular biology (which AIs would not share).

Edward Fredkin argues that "artificial intelligence is the next stage in evolution", an idea first proposed by Samuel Butler's "Darwin among the Machines" (1863), and expanded upon by George Dyson in his book of the same name in 1998.[178]

References

Notes

[1] Definition of AI as the study of intelligent agents:

- Poole, Mackworth & Goebel 1998, p. 1 (http://people.cs.ubc.ca/~poole/ci/ch1.pdf), which provides the version that is used in this article. Note that they use the term "computational intelligence" as a synonym for artificial intelligence.
- Russell & Norvig (2003) (who prefer the term "rational agent") and write "The whole-agent view is now widely accepted in the field" (Russell & Norvig 2003, p. 55).
- Nilsson 1998

[2] The intelligent agent paradigm:

- Russell & Norvig 2003, pp. 27, 32–58, 968–972
- Poole, Mackworth & Goebel 1998, pp. 7–21
- Luger & Stubblefield 2004, pp. 235–240

The definition used in this article, in terms of goals, actions, perception and environment, is due to Russell & Norvig (2003). Other definitions also include knowledge and learning as additional criteria.

[3] Although there is some controversy on this point (see Crevier (1993, p. 50)), McCarthy states unequivocally "I came up with the term" in a c|net interview. (Skillings 2006)

[4] McCarthy's definition of AI:

- McCarthy 2007

[5] Pamela McCorduck (2004, pp. 424) writes of "the rough shattering of AI in subfields—vision, natural language, decision theory, genetic algorithms, robotics ... and these with own sub-subfield—that would hardly have anything to say to each other."

[6] This list of intelligent traits is based on the topics covered by the major AI textbooks, including:

- Russell & Norvig 2003
- Luger & Stubblefield 2004
- Poole, Mackworth & Goebel 1998
- Nilsson 1998

[7] General intelligence (strong AI) is discussed in popular introductions to AI:

- Kurzweil 1999 and Kurzweil 2005

[8] See the Dartmouth proposal, under Philosophy, below.

[9] This is a central idea of Pamela McCorduck's *Machines That Think*. She writes: "I like to think of artificial intelligence as the scientific apotheosis of a venerable cultural tradition." (McCorduck 2004, p. 34) "Artificial intelligence in one form or another is an idea that has pervaded Western intellectual history, a dream in urgent need of being realized." (McCorduck 2004, p. xviii) "Our history is full of attempts—nutty, eerie, comical, earnest, legendary and real—to make artificial intelligences, to reproduce what is the essential us—bypassing the ordinary means. Back and forth between myth and reality, our imaginations supplying what our workshops couldn't, we have engaged for a long time in this odd form of self-reproduction." (McCorduck 2004, p. 3) She traces the desire back to its Hellenistic roots and calls it the urge to "forge the Gods." (McCorduck 2004, pp. 340–400)

[10] The optimism referred to includes the predictions of early AI researchers (see optimism in the history of AI) as well as the ideas of modern transhumanists such as Ray Kurzweil.

[11] The "setbacks" referred to include the ALPAC report of 1966, the abandonment of perceptrons in 1970, the Lighthill Report of 1973 and the collapse of the lisp machine market in 1987.

[12] AI applications widely used behind the scenes:

- Russell & Norvig 2003, p. 28
- Kurzweil 2005, p. 265
- NRC 1999, pp. 216–222

[13] AI in myth:

- McCorduck 2004, pp. 4–5
- Russell & Norvig 2003, p. 939

[14] Cult images as artificial intelligence:

- Crevier (1993, p. 1) (statue of Amun)
- McCorduck (2004, pp. 6–9)

These were the first machines to be believed to have true intelligence and consciousness. Hermes Trismegistus expressed the common belief that with these statues, craftsman had reproduced "the true nature of the gods", their *sensus* and *spiritus*. McCorduck makes the connection between sacred automatons and Mosaic law (developed around the same time), which expressly forbids the worship of robots (McCorduck 2004, pp. 6–9)

[15] Humanoid automata:

Yan Shi:

- Needham 1986, p. 53

Hero of Alexandria:

- McCorduck 2004, p. 6

Al-Jazari:

- "A Thirteenth Century Programmable Robot" (http://www.shef.ac.uk/marcoms/eview/articles58/robot.html). Shef.ac.uk. . Retrieved 25 April 2009.

Wolfgang von Kempelen:

- McCorduck 2004, p. 17

[16] Artificial beings:

Jābir ibn Hayyān's Takwin:

- O'Connor, Kathleen Malone (1994). *The alchemical creation of life (takwin) and other concepts of Genesis in medieval Islam* (http://repository.upenn.edu/dissertations/AAI9503804). University of Pennsylvania. . Retrieved 10 January 2007.

Judah Loew's Golem:

- McCorduck 2004, pp. 15–16
- Buchanan 2005, p. 50

Paracelsus' Homunculus:

- McCorduck 2004, pp. 13–14

[17] AI in early science fiction.

- McCorduck 2004, pp. 17–25

[18] This insight, that digital computers can simulate any process of formal reasoning, is known as the Church–Turing thesis.

[19] Formal reasoning:

- Berlinski, David (2000). *The Advent of the Algorithm*. Harcourt Books. ISBN 0-15-601391-6. OCLC 46890682.

[20] AI's immediate precursors:

- McCorduck 2004, pp. 51–107
- Crevier 1993, pp. 27–32
- Russell & Norvig 2003, pp. 15, 940
- Moravec 1988, p. 3

See also Cybernetics and early neural networks (in History of artificial intelligence). Among the researchers who laid the foundations of AI were Alan Turing, John Von Neumann, Norbert Wiener, Claude Shannon, Warren McCullough, Walter Pitts and Donald Hebb.

[21] Dartmouth conference:

- McCorduck 2004, pp. 111–136
- Crevier 1993, pp. 47–49, who writes "the conference is generally recognized as the official birthdate of the new science."
- Russell & Norvig 2003, p. 17, who call the conference "the birth of artificial intelligence."
- NRC 1999, pp. 200–201

[22] Hegemony of the Dartmouth conference attendees:

- Russell & Norvig 2003, p. 17, who write "for the next 20 years the field would be dominated by these people and their students."
- McCorduck 2004, pp. 129–130

[23] Russell and Norvig write "it was astonishing whenever a computer did anything kind of smartish." Russell & Norvig 2003, p. 18

[24] "Golden years" of AI (successful symbolic reasoning programs 1956–1973):

- McCorduck 2004, pp. 243–252
- Crevier 1993, pp. 52–107
- Moravec 1988, p. 9
- Russell & Norvig 2003, pp. 18–21

The programs described are Daniel Bobrow's STUDENT, Newell and Simon's Logic Theorist and Terry Winograd's SHRDLU.

[25] DARPA pours money into undirected pure research into AI during the 1960s:

- McCorduck 2004, pp. 131
- Crevier 1993, pp. 51, 64–65
- NRC 1999, pp. 204–205

[26] AI in England:

- Howe 1994

[27] Optimism of early AI:

- Herbert Simon quote: Simon 1965, p. 96 quoted in Crevier 1993, p. 109.
- Marvin Minsky quote: Minsky 1967, p. 2 quoted in Crevier 1993, p. 109.

[28] See The problems (in History of artificial intelligence)

[29] First AI Winter, Mansfield Amendment, Lighthill report

- Crevier 1993, pp. 115–117
- Russell & Norvig 2003, p. 22
- NRC 1999, pp. 212–213
- Howe 1994

[30] Expert systems:

- ACM 1998, I.2.1,
- Russell & Norvig 2003, pp. 22–24
- Luger & Stubblefield 2004, pp. 227–331,
- Nilsson 1998, chpt. 17.4
- McCorduck 2004, pp. 327–335, 434–435
- Crevier 1993, pp. 145–62, 197–203

[31] Boom of the 1980s: rise of expert systems, Fifth Generation Project, Alvey, MCC, SCI:

- McCorduck 2004, pp. 426–441
- Crevier 1993, pp. 161–162,197–203, 211, 240
- Russell & Norvig 2003, p. 24
- NRC 1999, pp. 210–211

[32] Second AI winter:

- McCorduck 2004, pp. 430–435
- Crevier 1993, pp. 209–210
- NRC 1999, pp. 214–216

[33] Formal methods are now preferred ("Victory of the neats"):

- Russell & Norvig 2003, pp. 25–26
- McCorduck 2004, pp. 486–487

[34] McCorduck 2004, pp. 480–483

[35] DARPA Grand Challenge – home page (http://www.darpa.mil/grandchallenge/)

[36] "Welcome" (http://archive.darpa.mil/grandchallenge/). Archive.darpa.mil. . Retrieved 31 October 2011.

[37] Markoff, John (16 February 2011). "On 'Jeopardy!' Watson Win Is All but Trivial" (http://www.nytimes.com/2011/02/17/science/17jeopardy-watson.html). *The New York Times*. .

[38] Kinect's AI breakthrough explained (http://www.i-programmer.info/news/105-artificial-intelligence/2176-kinects-ai-breakthrough-explained.html)

[39] Problem solving, puzzle solving, game playing and deduction:

- Russell & Norvig 2003, chpt. 3–9,
- Poole, Mackworth & Goebel 1998, chpt. 2,3,7,9,
- Luger & Stubblefield 2004, chpt. 3,4,6,8,
- Nilsson 1998, chpt. 7–12

[40] Uncertain reasoning:

- Russell & Norvig 2003, pp. 452–644,
- Poole, Mackworth & Goebel 1998, pp. 345–395,
- Luger & Stubblefield 2004, pp. 333–381,
- Nilsson 1998, chpt. 19

[41] Intractability and efficiency and the combinatorial explosion:

- Russell & Norvig 2003, pp. 9, 21–22

[42] Psychological evidence of sub-symbolic reasoning:

- Wason & Shapiro (1966) showed that people do poorly on completely abstract problems, but if the problem is restated to allow the use of intuitive social intelligence, performance dramatically improves. (See Wason selection task)

- Kahneman, Slovic & Tversky (1982) have shown that people are terrible at elementary problems that involve uncertain reasoning. (See list of cognitive biases for several examples).
- Lakoff & Núñez (2000) have controversially argued that even our skills at mathematics depend on knowledge and skills that come from "the body", i.e. sensorimotor and perceptual skills. (See Where Mathematics Comes From)

[43] Knowledge representation:

- ACM 1998, I.2.4,
- Russell & Norvig 2003, pp. 320–363,
- Poole, Mackworth & Goebel 1998, pp. 23–46, 69–81, 169–196, 235–277, 281–298, 319–345,
- Luger & Stubblefield 2004, pp. 227–243,
- Nilsson 1998, chpt. 18

[44] Knowledge engineering:

- Russell & Norvig 2003, pp. 260–266,
- Poole, Mackworth & Goebel 1998, pp. 199–233,
- Nilsson 1998, chpt. ~17.1–17.4

[45] Representing categories and relations: Semantic networks, description logics, inheritance (including frames and scripts):

- Russell & Norvig 2003, pp. 349–354,
- Poole, Mackworth & Goebel 1998, pp. 174–177,
- Luger & Stubblefield 2004, pp. 248–258,
- Nilsson 1998, chpt. 18.3

[46] Representing events and time:Situation calculus, event calculus, fluent calculus (including solving the frame problem):

- Russell & Norvig 2003, pp. 328–341,
- Poole, Mackworth & Goebel 1998, pp. 281–298,
- Nilsson 1998, chpt. 18.2

[47] Causal calculus:

- Poole, Mackworth & Goebel 1998, pp. 335–337

[48] Representing knowledge about knowledge: Belief calculus, modal logics:

- Russell & Norvig 2003, pp. 341–344,
- Poole, Mackworth & Goebel 1998, pp. 275–277

[49] Ontology:

- Russell & Norvig 2003, pp. 320–328

[50] Qualification problem:

- McCarthy & Hayes 1969
- Russell & Norvig 2003

While McCarthy was primarily concerned with issues in the logical representation of actions, Russell & Norvig 2003 apply the term to the more general issue of default reasoning in the vast network of assumptions underlying all our commonsense knowledge.

[51] Default reasoning and default logic, non-monotonic logics, circumscription, closed world assumption, abduction (Poole *et al.* places abduction under "default reasoning". Luger *et al.* places this under "uncertain reasoning"):

- Russell & Norvig 2003, pp. 354–360,
- Poole, Mackworth & Goebel 1998, pp. 248–256, 323–335,
- Luger & Stubblefield 2004, pp. 335–363,
- Nilsson 1998, ~18.3.3

[52] Breadth of commonsense knowledge:

- Russell & Norvig 2003, p. 21,
- Crevier 1993, pp. 113–114,
- Moravec 1988, p. 13,
- Lenat & Guha 1989 (Introduction)

[53] Dreyfus & Dreyfus 1986

[54] Gladwell 2005

[55] Expert knowledge as embodied intuition:

- Dreyfus & Dreyfus 1986 (Hubert Dreyfus is a philosopher and critic of AI who was among the first to argue that most useful human knowledge was encoded sub-symbolically. See Dreyfus' critique of AI)
- Gladwell 2005 (Gladwell's *Blink* is a popular introduction to sub-symbolic reasoning and knowledge.)
- Hawkins & Blakeslee 2005 (Hawkins argues that sub-symbolic knowledge should be the primary focus of AI research.)

[56] Planning:

- ACM 1998, ~I.2.8,
- Russell & Norvig 2003, pp. 375–459,

- Poole, Mackworth & Goebel 1998, pp. 281–316,
- Luger & Stubblefield 2004, pp. 314–329,
- Nilsson 1998, chpt. 10.1–2, 22

[57] Information value theory:

- Russell & Norvig 2003, pp. 600–604

[58] Classical planning:

- Russell & Norvig 2003, pp. 375–430,
- Poole, Mackworth & Goebel 1998, pp. 281–315,
- Luger & Stubblefield 2004, pp. 314–329,
- Nilsson 1998, chpt. 10.1–2, 22

[59] Planning and acting in non-deterministic domains: conditional planning, execution monitoring, replanning and continuous planning:

- Russell & Norvig 2003, pp. 430–449

[60] Multi-agent planning and emergent behavior:

- Russell & Norvig 2003, pp. 449–455

[61] Learning:

- ACM 1998, I.2.6,
- Russell & Norvig 2003, pp. 649–788,
- Poole, Mackworth & Goebel 1998, pp. 397–438,
- Luger & Stubblefield 2004, pp. 385–542,
- Nilsson 1998, chpt. 3.3 , 10.3, 17.5, 20

[62] Alan Turing discussed the centrality of learning as early as 1950, in his classic paper Computing Machinery and Intelligence. (Turing 1950)

[63] (pdf scanned copy of the original) (http://world.std.com/~rjs/indinf56.pdf) (version published in 1957, An Inductive Inference Machine," IRE Convention Record, Section on Information Theory, Part 2, pp. 56–62)

[64] Reinforcement learning:

- Russell & Norvig 2003, pp. 763–788
- Luger & Stubblefield 2004, pp. 442–449

[65] Computational learning theory:

- CITATION IN PROGRESS.

[66] Natural language processing:

- ACM 1998, I.2.7
- Russell & Norvig 2003, pp. 790–831
- Poole, Mackworth & Goebel 1998, pp. 91–104
- Luger & Stubblefield 2004, pp. 591–632

[67] Applications of natural language processing, including information retrieval (i.e. text mining) and machine translation:

- Russell & Norvig 2003, pp. 840–857,
- Luger & Stubblefield 2004, pp. 623–630

[68] Robotics:

- ACM 1998, I.2.9,
- Russell & Norvig 2003, pp. 901–942,
- Poole, Mackworth & Goebel 1998, pp. 443–460

[69] Moving and configuration space:

- Russell & Norvig 2003, pp. 916–932

[70] Tecuci, G. (2012), Artificial intelligence. WIREs Comp Stat, 4: 168–180. doi: 10.1002/wics.200

[71] Robotic mapping (localization, etc):

- Russell & Norvig 2003, pp. 908–915

[72] Machine perception:

- Russell & Norvig 2003, pp. 537–581, 863–898
- Nilsson 1998, ~chpt. 6

[73] Computer vision:

- ACM 1998, I.2.10
- Russell & Norvig 2003, pp. 863–898
- Nilsson 1998, chpt. 6

[74] Speech recognition:

- ACM 1998, ~I.2.7
- Russell & Norvig 2003, pp. 568–578

[75] Object recognition:

- Russell & Norvig 2003, pp. 885–892

[76] "Kismet" (http://www.ai.mit.edu/projects/humanoid-robotics-group/kismet/kismet.html). MIT Artificial Intelligence Laboratory, Humanoid Robotics Group. .

[77] Thro, Ellen (1993). *Robotics*. New York.

[78] Edelson, Edward (1991). *The Nervous System*. New York: Remmel Nunn.

[79] Tao, Jianhua; Tieniu Tan (2005). "Affective Computing: A Review". *Affective Computing and Intelligent Interaction*. **LNCS 3784**. Springer. pp. 981–995. doi:10.1007/11573548.

[80] James, William (1884). "What is Emotion". *Mind* **9**: 188–205. doi:10.1093/mind/os-IX.34.188. Cited by Tao and Tan.

[81] "Affective Computing" (http://affect.media.mit.edu/pdfs/95.picard.pdf) MIT Technical Report #321 (Abstract (http://vismod.media.mit.edu/pub/tech-reports/TR-321-ABSTRACT.html)), 1995

[82] Kleine-Cosack, Christian (October 2006). "Recognition and Simulation of Emotions" (http://web.archive.org/web/20080528135730/http://ls12-www.cs.tu-dortmund.de/~fink/lectures/SS06/human-robot-interaction/Emotion-RecognitionAndSimulation.pdf) (PDF). Archived from the original (http://ls12-www.cs.tu-dortmund.de//~fink/lectures/SS06/human-robot-interaction/Emotion-RecognitionAndSimulation.pdf) on 28 May 2008. . Retrieved 13 May 2008. "The introduction of emotion to computer science was done by Pickard (sic) who created the field of affective computing."

[83] Diamond, David (December 2003). "The Love Machine; Building computers that care" (http://www.wired.com/wired/archive/11.12/love.html). Wired. Archived (http://web.archive.org/web/20080518185630/http://www.wired.com/wired/archive/11.12/love.html) from the original on 18 May 2008. . Retrieved 13 May 2008. "Rosalind Picard, a genial MIT professor, is the field's godmother; her 1997 book, Affective Computing, triggered an explosion of interest in the emotional side of computers and their users."

[84] Emotion and affective computing:

- Minsky 2006

[85] Gerald Edelman, Igor Aleksander and others have both argued that artificial consciousness is required for strong AI. (Aleksander 1995; Edelman 2007)

[86] Artificial brain arguments: AI requires a simulation of the operation of the human brain

- Russell & Norvig 2003, p. 957
- Crevier 1993, pp. 271 and 279

A few of the people who make some form of the argument:

- Moravec 1988
- Kurzweil 2005, p. 262
- Hawkins & Blakeslee 2005

The most extreme form of this argument (the brain replacement scenario) was put forward by Clark Glymour in the mid-70s and was touched on by Zenon Pylyshyn and John Searle in 1980.

[87] AI complete: Shapiro 1992, p. 9

[88] Nils Nilsson writes: "Simply put, there is wide disagreement in the field about what AI is all about" (Nilsson 1983, p. 10).

[89] Biological intelligence vs. intelligence in general:

- Russell & Norvig 2003, pp. 2–3, who make the analogy with aeronautical engineering.
- McCorduck 2004, pp. 100–101, who writes that there are "two major branches of artificial intelligence: one aimed at producing intelligent behavior regardless of how it was accomplioshed, and the other aimed at modeling intelligent processes found in nature, particularly human ones."
- Kolata 1982, a paper in *Science*, which describes McCathy's indifference to biological models. Kolata quotes McCarthy as writing: "This is AI, so we don't care if it's psychologically real" (http://books.google.com/books?id=PEkqAAAAMAAJ&q="we+don't+care+if+it's+psychologically+real"&dq="we+don't+care+if+it's+psychologically+real"&output=html&pgis=1). McCarthy recently reiterated his position at the AI@50 conference where he said "Artificial intelligence is not, by definition, simulation of human intelligence" (Maker 2006).

[90] Neats vs. scruffies:

- McCorduck 2004, pp. 421–424, 486–489
- Crevier 1993, pp. 168
- Nilsson 1983, pp. 10–11

[91] Symbolic vs. sub-symbolic AI:

- Nilsson (1998, p. 7), who uses the term "sub-symbolic".

[92] Haugeland 1985, p. 255

[93] http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.38.8384&rep=rep1&type=pdf

[94] Pei Wang (2008). *Artificial general intelligence, 2008: proceedings of the First AGI Conference* (http://books.google.com/books?id=a_ZR81Z25z0C&pg=PA63). IOS Press. p. 63. ISBN 978-1-58603-833-5. . Retrieved 31 October 2011.

[95] Haugeland 1985, pp. 112–117

[96] The most dramatic case of sub-symbolic AI being pushed into the background was the devastating critique of perceptrons by Marvin Minsky and Seymour Papert in 1969. See History of AI, AI winter, or Frank Rosenblatt.

[97] Cognitive simulation, Newell and Simon, AI at CMU (then called Carnegie Tech):

- McCorduck 2004, pp. 139–179, 245–250, 322–323 (EPAM)
- Crevier 1993, pp. 145–149

[98] Soar (history):

- McCorduck 2004, pp. 450–451
- Crevier 1993, pp. 258–263

[99] McCarthy and AI research at SAIL and SRI International:

- McCorduck 2004, pp. 251–259
- Crevier 1993

[100] AI research at Edinburgh and in France, birth of Prolog:

- Crevier 1993, pp. 193–196
- Howe 1994

[101] AI at MIT under Marvin Minsky in the 1960s :

- McCorduck 2004, pp. 259–305
- Crevier 1993, pp. 83–102, 163–176
- Russell & Norvig 2003, p. 19

[102] Cyc:

- McCorduck 2004, p. 489, who calls it "a determinedly scruffy enterprise"
- Crevier 1993, pp. 239–243
- Russell & Norvig 2003, p. 363–365
- Lenat & Guha 1989

[103] Knowledge revolution:

- McCorduck 2004, pp. 266–276, 298–300, 314, 421
- Russell & Norvig 2003, pp. 22–23

[104] Embodied approaches to AI:

- McCorduck 2004, pp. 454–462
- Brooks 1990
- Moravec 1988

[105] Revival of connectionism:

- Crevier 1993, pp. 214–215
- Russell & Norvig 2003, p. 25

[106] Computational intelligence

- IEEE Computational Intelligence Society (http://www.ieee-cis.org/)

[107] Pat Langley, "The changing science of machine learning" (http://www.springerlink.com/content/j067h855n8223338/), *Machine Learning*, Volume 82, Number 3, 275–279, doi:10.1007/s10994-011-5242-y

[108] Agent architectures, hybrid intelligent systems:

- Russell & Norvig (2003, pp. 27, 932, 970–972)
- Nilsson (1998, chpt. 25)

[109] Hierarchical control system:

- Albus, J. S. 4-D/RCS reference model architecture for unmanned ground vehicles. (http://www.isd.mel.nist.gov/documents/albus/4DRCS.pdf) In G Gerhart, R Gunderson, and C Shoemaker, editors, Proceedings of the SPIE AeroSense Session on Unmanned Ground Vehicle Technology, volume 3693, pages 11—20

[110] Subsumption architecture:

- CITATION IN PROGRESS.

[111] Search algorithms:

- Russell & Norvig 2003, pp. 59–189
- Poole, Mackworth & Goebel 1998, pp. 113–163
- Luger & Stubblefield 2004, pp. 79–164, 193–219
- Nilsson 1998, chpt. 7–12

[112] Forward chaining, backward chaining, Horn clauses, and logical deduction as search:

- Russell & Norvig 2003, pp. 217–225, 280–294
- Poole, Mackworth & Goebel 1998, pp. ~46–52
- Luger & Stubblefield 2004, pp. 62–73

- Nilsson 1998, chpt. 4.2, 7.2

[113] State space search and planning:

- Russell & Norvig 2003, pp. 382–387
- Poole, Mackworth & Goebel 1998, pp. 298–305
- Nilsson 1998, chpt. 10.1–2

[114] Uninformed searches (breadth first search, depth first search and general state space search):

- Russell & Norvig 2003, pp. 59–93
- Poole, Mackworth & Goebel 1998, pp. 113–132
- Luger & Stubblefield 2004, pp. 79–121
- Nilsson 1998, chpt. 8

[115] Heuristic or informed searches (e.g., greedy best first and A*):

- Russell & Norvig 2003, pp. 94–109,
- Poole, Mackworth & Goebel 1998, pp. pp. 132–147,
- Luger & Stubblefield 2004, pp. 133–150,
- Nilsson 1998, chpt. 9

[116] Optimization searches:

- Russell & Norvig 2003, pp. 110–116,120–129
- Poole, Mackworth & Goebel 1998, pp. 56–163
- Luger & Stubblefield 2004, pp. 127–133

[117] Artificial life and society based learning:

- Luger & Stubblefield 2004, pp. 530–541

[118] Genetic programming and genetic algorithms:

- Luger & Stubblefield 2004, pp. 509–530,
- Nilsson 1998, chpt. 4.2.
- Holland, John H. (1975). *Adaptation in Natural and Artificial Systems*. University of Michigan Press. ISBN 0-262-58111-6.
- Koza, John R. (1992). *Genetic Programming*. MIT Press. ISBN 0-262-11170-5.
- Poli, R., Langdon, W. B., McPhee, N. F. (2008). *A Field Guide to Genetic Programming*. Lulu.com, freely available from http://www.gp-field-guide.org.uk/. ISBN 978-1-4092-0073-4.

[119] Logic:

- ACM 1998, ~I.2.3,
- Russell & Norvig 2003, pp. 194–310,
- Luger & Stubblefield 2004, pp. 35–77,
- Nilsson 1998, chpt. 13–16

[120] Satplan:

- Russell & Norvig 2003, pp. 402–407,
- Poole, Mackworth & Goebel 1998, pp. 300–301,
- Nilsson 1998, chpt. 21

[121] Explanation based learning, relevance based learning, inductive logic programming, case based reasoning:

- Russell & Norvig 2003, pp. 678–710,
- Poole, Mackworth & Goebel 1998, pp. 414–416,
- Luger & Stubblefield 2004, pp. ~422–442,
- Nilsson 1998, chpt. 10.3, 17.5

[122] Propositional logic:

- Russell & Norvig 2003, pp. 204–233,
- Luger & Stubblefield 2004, pp. 45–50
- Nilsson 1998, chpt. 13

[123] First-order logic and features such as equality:

- ACM 1998, ~I.2.4,
- Russell & Norvig 2003, pp. 240–310,
- Poole, Mackworth & Goebel 1998, pp. 268–275,
- Luger & Stubblefield 2004, pp. 50–62,
- Nilsson 1998, chpt. 15

[124] Fuzzy logic:

- Russell & Norvig 2003, pp. 526–527

[125] Subjective logic:

- CITATION IN PROGRESS.

[126] Stochastic methods for uncertain reasoning:

- ACM 1998, ~I.2.3,
- Russell & Norvig 2003, pp. 462–644,
- Poole, Mackworth & Goebel 1998, pp. 345–395,
- Luger & Stubblefield 2004, pp. 165–191, 333–381,
- Nilsson 1998, chpt. 19

[127] Bayesian networks:

- Russell & Norvig 2003, pp. 492–523,
- Poole, Mackworth & Goebel 1998, pp. 361–381,
- Luger & Stubblefield 2004, pp. ~182–190, ~363–379,
- Nilsson 1998, chpt. 19.3–4

[128] Bayesian inference algorithm:

- Russell & Norvig 2003, pp. 504–519,
- Poole, Mackworth & Goebel 1998, pp. 361–381,
- Luger & Stubblefield 2004, pp. ~363–379,
- Nilsson 1998, chpt. 19.4 & 7

[129] Bayesian learning and the expectation-maximization algorithm:

- Russell & Norvig 2003, pp. 712–724,
- Poole, Mackworth & Goebel 1998, pp. 424–433,
- Nilsson 1998, chpt. 20

[130] Bayesian decision theory and Bayesian decision networks:

- Russell & Norvig 2003, pp. 597–600

[131] Stochastic temporal models:

- Russell & Norvig 2003, pp. 537–581

Dynamic Bayesian networks:

- Russell & Norvig 2003, pp. 551–557

Hidden Markov model:

- (Russell & Norvig 2003, pp. 549–551)

Kalman filters:

- Russell & Norvig 2003, pp. 551–557

[132] decision theory and decision analysis:

- Russell & Norvig 2003, pp. 584–597,
- Poole, Mackworth & Goebel 1998, pp. 381–394

[133] Markov decision processes and dynamic decision networks:

- Russell & Norvig 2003, pp. 613–631

[134] Game theory and mechanism design:

- Russell & Norvig 2003, pp. 631–643

[135] Statistical learning methods and classifiers:

- Russell & Norvig 2003, pp. 712–754,
- Luger & Stubblefield 2004, pp. 453–541

[136] Neural networks and connectionism:

- Russell & Norvig 2003, pp. 736–748,
- Poole, Mackworth & Goebel 1998, pp. 408–414,
- Luger & Stubblefield 2004, pp. 453–505,
- Nilsson 1998, chpt. 3

[137] kernel methods such as the support vector machine, Kernel methods:

- Russell & Norvig 2003, pp. 749–752

[138] K-nearest neighbor algorithm:

- Russell & Norvig 2003, pp. 733–736

[139] Gaussian mixture model:

- Russell & Norvig 2003, pp. 725–727

[140] Naive Bayes classifier:

- Russell & Norvig 2003, pp. 718

[141] Decision tree:

- Russell & Norvig 2003, pp. 653–664,
- Poole, Mackworth & Goebel 1998, pp. 403–408,
- Luger & Stubblefield 2004, pp. 408–417

[142] Classifier performance:

- van der Walt & Bernard 2006

[143] Backpropagation:

- Russell & Norvig 2003, pp. 744–748,
- Luger & Stubblefield 2004, pp. 467–474,
- Nilsson 1998, chpt. 3.3

[144] Feedforward neural networks, perceptrons and radial basis networks:

- Russell & Norvig 2003, pp. 739–748, 758
- Luger & Stubblefield 2004, pp. 458–467

[145] Recurrent neural networks, Hopfield nets:

- Russell & Norvig 2003, p. 758
- Luger & Stubblefield 2004, pp. 474–505

[146] Competitive learning, Hebbian coincidence learning, Hopfield networks and attractor networks:

- Luger & Stubblefield 2004, pp. 474–505

[147] Hierarchical temporal memory:

- Hawkins & Blakeslee 2005

[148] Control theory:

- ACM 1998, ~I.2.8,
- Russell & Norvig 2003, pp. 926–932

[149] Lisp:

- Luger & Stubblefield 2004, pp. 723–821
- Crevier 1993, pp. 59–62,
- Russell & Norvig 2003, p. 18

[150] Prolog:

- Poole, Mackworth & Goebel 1998, pp. 477–491,
- Luger & Stubblefield 2004, pp. 641–676, 575–581

[151] The Turing test:
Turing's original publication:

- Turing 1950

Historical influence and philosophical implications:

- Haugeland 1985, pp. 6–9
- Crevier 1993, p. 24
- McCorduck 2004, pp. 70–71
- Russell & Norvig 2003, pp. 2–3 and 948

[152] Subject matter expert Turing test:

- CITATION IN PROGRESS.

[153] Rajani, Sandeep (2011). "Artificial Intelligence - Man or Machine" (http://www.csjournals.com/IJITKM/PDF 4-1/35.Sandeep Rajani.pdf). *International Journal of Information Technology and Knowlede Management* **4** (1): 173-176. . Retrieved 24 September 2012.

[154] Game AI:

- CITATION IN PROGRESS.

[155] Mathematical definitions of intelligence:

- Jose Hernandez-Orallo (2000). "Beyond the Turing Test". *Journal of Logic, Language and Information* **9** (4): 447–466. doi:10.1023/A:1008367325700. CiteSeerX: 10.1.1.44.8943 (http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.44.8943).
- D L Dowe and A R Hajek (1997). "A computational extension to the Turing Test" (http://www.csse.monash.edu.au/publications/1997/tr-cs97-322-abs.html). *Proceedings of the 4th Conference of the Australasian Cognitive Science jSociety*. . Retrieved 21 July 2009.
- J Hernandez-Orallo and D L Dowe (2010). "Measuring Universal Intelligence: Towards an Anytime Intelligence Test". *Artificial Intelligence Journal* **174** (18): 1508–1539. doi:10.1016/j.artint.2010.09.006.

[156] "AI set to exceed human brain power" (http://www.cnn.com/2006/TECH/science/07/24/ai.bostrom/) (web article). CNN. 26 July 2006. Archived (http://web.archive.org/web/20080219001624/http://www.cnn.com/2006/TECH/science/07/24/ai.bostrom/) from the original on 19 February 2008. . Retrieved 26 February 2008.

[157] Brooks, R.A., "How to build complete creatures rather than isolated cognitive simulators," in K. VanLehn (ed.), Architectures for Intelligence, pp. 225–239, Lawrence Erlbaum Associates, Hillsdale, NJ, 1991.

[158] Hacking Roomba » Search Results » atmel (http://hackingroomba.com/?s=atmel)

[159] Philosophy of AI. All of these positions in this section are mentioned in standard discussions of the subject, such as:

- Russell & Norvig 2003, pp. 947–960
- Fearn 2007, pp. 38–55

[160] Dartmouth proposal:

- McCarthy et al. 1955 (the original proposal)
- Crevier 1993, p. 49 (historical significance)

[161] The physical symbol systems hypothesis:

- Newell & Simon 1976, p. 116
- McCorduck 2004, p. 153
- Russell & Norvig 2003, p. 18

[162] Dreyfus criticized the necessary condition of the physical symbol system hypothesis, which he called the "psychological assumption": "The mind can be viewed as a device operating on bits of information according to formal rules". (Dreyfus 1992, p. 156)

[163] Dreyfus' critique of artificial intelligence:

- Dreyfus 1972, Dreyfus & Dreyfus 1986
- Crevier 1993, pp. 120–132
- McCorduck 2004, pp. 211–239
- Russell & Norvig 2003, pp. 950–952,

[164] This is a paraphrase of the relevant implication of Gödel's theorems.

[165] The Mathematical Objection:

- Russell & Norvig 2003, p. 949
- McCorduck 2004, pp. 448–449

Making the Mathematical Objection:

- Lucas 1961
- Penrose 1989

Refuting Mathematical Objection:

- Turing 1950 under "(2) The Mathematical Objection"
- Hofstadter 1979

Background:

- Gödel 1931, Church 1936, Kleene 1935, Turing 1937

[166] This version is from Searle (1999), and is also quoted in Dennett 1991, p. 435. Searle's original formulation was "The appropriately programmed computer really is a mind, in the sense that computers given the right programs can be literally said to understand and have other cognitive states." (Searle 1980, p. 1). Strong AI is defined similarly by Russell & Norvig (2003, p. 947): "The assertion that machines could possibly act intelligently (or, perhaps better, act as if they were intelligent) is called the 'weak AI' hypothesis by philosophers, and the assertion that machines that do so are actually thinking (as opposed to simulating thinking) is called the 'strong AI' hypothesis."

[167] Searle's Chinese room argument:

- Searle 1980. Searle's original presentation of the thought experiment.
- Searle 1999.

Discussion:

- Russell & Norvig 2003, pp. 958–960
- McCorduck 2004, pp. 443–445
- Crevier 1993, pp. 269–271

[168] Robot rights:

- Russell & Norvig 2003, p. 964
- "Robots could demand legal rights" (http://news.bbc.co.uk/2/hi/technology/6200005.stm). *BBC News*. 21 December 2006. . Retrieved 3 February 2011.

Prematurity of:

- Henderson, Mark (24 April 2007). "Human rights for robots? We're getting carried away" (http://www.timesonline.co.uk/tol/news/uk/science/article1695546.ece). *The Times Online* (London). .

In fiction:

- McCorduck (2004, p. 190-25) discusses *Frankenstein* and identifies the key ethical issues as scientific hubris and the suffering of the monster, i.e. robot rights.

[169] Independent documentary Plug & Pray, featuring Joseph Weizenbaum and Raymond Kurzweil (http://www.plugandpray-film.de/en/content.html)

[170] Ford, Martin R. (2009), *The Lights in the Tunnel: Automation, Accelerating Technology and the Economy of the Future* (http://www.thelightsinthetunnel.com), Acculant Publishing, ISBN 978-1448659814, . *(e-book available free online* (http://www.thelightsinthetunnel.com/).*)*

[171] "Machine Learning: A Job Killer?" (http://econfuture.wordpress.com/2011/04/14/machine-learning-a-job-killer/)

[172] AI could decrease the demand for human labor:

- Russell & Norvig 2003, pp. 960–961
- Ford, Martin (2009). *The Lights in the Tunnel: Automation, Accelerating Technology and the Economy of the Future* (http://www.thelightsinthetunnel.com). Acculant Publishing. ISBN 978-1-4486-5981-4. .

[173] In the early 70s, Kenneth Colby presented a version of Weizenbaum's ELIZA known as DOCTOR which he promoted as a serious therapeutic tool. (Crevier 1993, pp. 132–144)

[174] Joseph Weizenbaum's critique of AI:

- Weizenbaum 1976
- Crevier 1993, pp. 132–144
- McCorduck 2004, pp. 356–373
- Russell & Norvig 2003, p. 961

Weizenbaum (the AI researcher who developed the first chatterbot program, ELIZA) argued in 1976 that the misuse of artificial intelligence has the potential to devalue human life.

[175] Technological singularity:

- Vinge 1993
- Kurzweil 2005
- Russell & Norvig 2003, p. 963

[176] Transhumanism:

- Moravec 1988
- Kurzweil 2005
- Russell & Norvig 2003, p. 963

[177] Rubin, Charles (Spring 2003). "Artificial Intelligence and Human Nature" (http://www.thenewatlantis.com/publications/artificial-intelligence-and-human-nature). *The New Atlantis* **1**: 88–100. .

[178] AI as evolution:

- Edward Fredkin is quoted in McCorduck (2004, p. 401).
- Butler, Samuel (13 June 1863). *the Press* (Christchurch, New Zealand). http://www.nzetc.org/tm/scholarly/tei-ButFir-t1-g1-t1-g1-t4-body.html, Letter to the Editor.
- Dyson, George (1998). *Darwin among the Machiens*. Allan Lane Science. ISBN 0-7382-0030-1.

References

AI textbooks

- Luger, George; Stubblefield, William (2004). *Artificial Intelligence: Structures and Strategies for Complex Problem Solving* (http://www.cs.unm.edu/~luger/ai-final/tocfull.html) (5th ed.). The Benjamin/Cummings Publishing Company, Inc.. ISBN 0-8053-4780-1.
- Neapolitan, Richard; Jiang, Xia (2012). *Contemporary Artificial Intelligence* (http://www.crcpress.com/product/isbn/9781439844694). Chapman & Hall/CRC. ISBN 978-143984-469-4.
- Nilsson, Nils (1998). *Artificial Intelligence: A New Synthesis*. Morgan Kaufmann Publishers. ISBN 978-1-55860-467-4.
- Russell, Stuart J.; Norvig, Peter (2003), *Artificial Intelligence: A Modern Approach* (http://aima.cs.berkeley.edu/) (2nd ed.), Upper Saddle River, New Jersey: Prentice Hall, ISBN 0-13-790395-2
- Poole, David; Mackworth, Alan; Goebel, Randy (1998). *Computational Intelligence: A Logical Approach* (http://www.cs.ubc.ca/spider/poole/ci.html). New York: Oxford University Press. ISBN 0-19-510270-3.
- Winston, Patrick Henry (1984). *Artificial Intelligence*. Reading, Massachusetts: Addison-Wesley. ISBN 0-201-08259-4.

History of AI

- Crevier, Daniel (1993), *AI: The Tumultuous Search for Artificial Intelligence*, New York, NY: BasicBooks, ISBN 0-465-02997-3
- McCorduck, Pamela (2004), *Machines Who Think* (http://www.pamelamc.com/html/machines_who_think.html) (2nd ed.), Natick, MA: A. K. Peters, Ltd., ISBN 1-56881-205-1

Nilsson, Nils (2010), The Quest for Artificial Intelligence: A History of Ideas and Achievements, New York, NY: Cambridge University Press, ISBN 978052112293

Other sources

- "ACM Computing Classification System: Artificial intelligence" (http://www.acm.org/class/1998/I.2.html). ACM. 1998. Retrieved 30 August 2007.
- Aleksander, Igor (1995). *Artificial Neuroconsciousness: An Update* (http://web.archive.org/web/19970302014628/http://www.ee.ic.ac.uk/research/neural/publications/iwann.html). IWANN. Archived from the original (http://www.ee.ic.ac.uk/research/neural/publications/iwann.html) on 2 March 1997. BibTex (http://dblp.uni-trier.de/rec/bibtex/conf/iwann/Aleksander95) Internet Archive (http://web.archive.org/web/19970302014628/http://www.ee.ic.ac.uk/research/neural/publications/iwann.html)
- Brooks, Rodney (1990). "Elephants Don't Play Chess" (http://people.csail.mit.edu/brooks/papers/elephants.pdf) (PDF). *Robotics and Autonomous Systems* **6**: 3–15. doi:10.1016/S0921-8890(05)80025-9. Archived (http://web.archive.org/web/20070809020912/http://people.csail.mit.edu/brooks/papers/elephants.pdf) from the original on 9 August 2007. Retrieved 30 August 2007..
- Buchanan, Bruce G. (2005). "A (Very) Brief History of Artificial Intelligence" (http://www.aaai.org/AITopics/assets/PDF/AIMag26-04-016.pdf) (PDF). *AI Magazine*: 53–60. Archived (http://web.archive.org/web/20070926023314/http://www.aaai.org/AITopics/assets/PDF/AIMag26-04-016.pdf) from the original on 26 September 2007. Retrieved 30 August 2007.
- Dennett, Daniel (1991). *Consciousness Explained*. The Penguin Press. ISBN 0-7139-9037-6.
- Dreyfus, Hubert (1972). *What Computers Can't Do*. New York: MIT Press. ISBN 0-06-011082-1.
- Dreyfus, Hubert (1979). *What Computers* Still *Can't Do*. New York: MIT Press. ISBN 0-262-04134-0.
- Dreyfus, Hubert; Dreyfus, Stuart (1986). *Mind over Machine: The Power of Human Intuition and Expertise in the Era of the Computer*. Oxford, UK: Blackwell. ISBN 0-02-908060-6.
- Dreyfus, Hubert (1992). *What Computers* Still *Can't Do*. New York: MIT Press. ISBN 0-262-54067-3.
- Edelman, Gerald (23 November 2007). "Gerald Edelman – Neural Darwinism and Brain-based Devices" (http://lis.epfl.ch/resources/podcast/2007/11/gerald-edelman-neural-darwinism-and.html). Talking Robots.
- Fearn, Nicholas (2007). *The Latest Answers to the Oldest Questions: A Philosophical Adventure with the World's Greatest Thinkers*. New York: Grove Press. ISBN 0-8021-1839-9.
- Forster, Dion (2006). "Self validating consciousness in strong artificial intelligence: An African theological contribution" (http://www.spirituality.org.za/files/D Forster doctorate.pdf). Pretoria: University of South Africa.
- Gladwell, Malcolm (2005). *Blink*. New York: Little, Brown and Co.. ISBN 0-316-17232-4.
- Haugeland, John (1985). *Artificial Intelligence: The Very Idea*. Cambridge, Mass.: MIT Press. ISBN 0-262-08153-9.
- Hawkins, Jeff; Blakeslee, Sandra (2005). *On Intelligence*. New York, NY: Owl Books. ISBN 0-8050-7853-3.
- Hofstadter, Douglas (1979). *Gödel, Escher, Bach: an Eternal Golden Braid*. New York, NY: Vintage Books. ISBN 0-394-74502-7.
- Howe, J. (November 1994). "Artificial Intelligence at Edinburgh University: a Perspective" (http://www.inf.ed.ac.uk/about/AIhistory.html). Retrieved 30 August 2007..

- Kahneman, Daniel; Slovic, D.; Tversky, Amos (1982). *Judgment under uncertainty: Heuristics and biases*. New York: Cambridge University Press. ISBN 0-521-28414-7.
- Kolata, G. (1982). "How can computers get common sense?". *Science* **217** (4566): 1237–1238. doi:10.1126/science.217.4566.1237. PMID 17837639.
- Kurzweil, Ray (1999). *The Age of Spiritual Machines*. Penguin Books. ISBN 0-670-88217-8.
- Kurzweil, Ray (2005). *The Singularity is Near*. Penguin Books. ISBN 0-670-03384-7.
- Lakoff, George (1987). *Women, Fire, and Dangerous Things: What Categories Reveal About the Mind*. University of Chicago Press. ISBN 0-226-46804-6.
- Lakoff, George; Núñez, Rafael E. (2000). *Where Mathematics Comes From: How the Embodied Mind Brings Mathematics into Being*. Basic Books. ISBN 0-465-03771-2..
- Lenat, Douglas; Guha, R. V. (1989). *Building Large Knowledge-Based Systems*. Addison-Wesley. ISBN 0-201-51752-3.
- Lighthill, Professor Sir James (1973). "Artificial Intelligence: A General Survey". *Artificial Intelligence: a paper symposium*. Science Research Council.
- Lucas, John (1961). "Minds, Machines and Gödel" (http://users.ox.ac.uk/~jrlucas/Godel/mmg.html). In Anderson, A.R.. *Minds and Machines*. Archived (http://web.archive.org/web/20070819165214/http://users.ox.ac.uk/~jrlucas/Godel/mmg.html) from the original on 19 August 2007. Retrieved 30 August 2007.
- Maker, Meg Houston (2006). "AI@50: AI Past, Present, Future" (http://www.engagingexperience.com/2006/07/ai50_ai_past_pr.html). Dartmouth College. Archived (http://web.archive.org/web/20081008120238/http://www.engagingexperience.com/2006/07/ai50_ai_past_pr.html) from the original on 8 October 2008. Retrieved 16 October 2008.
- McCarthy, John; Minsky, Marvin; Rochester, Nathan; Shannon, Claude (1955). "A Proposal for the Dartmouth Summer Research Project on Artificial Intelligence" (http://www-formal.stanford.edu/jmc/history/dartmouth/dartmouth.html). Archived (http://web.archive.org/web/20070826230310/http://www-formal.stanford.edu/jmc/history/dartmouth/dartmouth.html) from the original on 26 August 2007. Retrieved 30 August 2007..
- McCarthy, John; Hayes, P. J. (1969). "Some philosophical problems from the standpoint of artificial intelligence" (http://www-formal.stanford.edu/jmc/mcchay69.html). *Machine Intelligence* **4**: 463–502. Archived (http://web.archive.org/web/20070810233856/http://www-formal.stanford.edu/jmc/mcchay69.html) from the original on 10 August 2007. Retrieved 30 August 2007.
- McCarthy, John (12 November 2007). "What Is Artificial Intelligence?" (http://www-formal.stanford.edu/jmc/whatisai/whatisai.html).
- Minsky, Marvin (1967). *Computation: Finite and Infinite Machines*. Englewood Cliffs, N.J.: Prentice-Hall. ISBN 0-13-165449-7.
- Minsky, Marvin (2006). *The Emotion Machine*. New York, NY: Simon & Schusterl. ISBN 0-7432-7663-9.
- Moravec, Hans (1976). "The Role of Raw Power in Intelligence" (http://www.frc.ri.cmu.edu/users/hpm/project.archive/general.articles/1975/Raw.Power.html). Retrieved 30 August 2007.
- Moravec, Hans (1988). *Mind Children*. Harvard University Press. ISBN 0-674-57616-0.
- NRC, (United States National Research Council) (1999). "Developments in Artificial Intelligence". *Funding a Revolution: Government Support for Computing Research*. National Academy Press.
- Needham, Joseph (1986). *Science and Civilization in China: Volume 2*. Caves Books Ltd..
- Newell, Allen; Simon, H. A. (1963). "GPS: A Program that Simulates Human Thought". In Feigenbaum, E.A.; Feldman, J.. *Computers and Thought*. New York: McGraw-Hill.
- Newell, Allen; Simon, H. A. (1976). "Computer Science as Empirical Inquiry: Symbols and Search" (http://www.rci.rutgers.edu/~cfs/472_html/AI_SEARCH/PSS/PSSH4.html). *Communications of the ACM*. **19**..
- Nilsson, Nils (1983), "Artificial Intelligence Prepares for 2001" (http://ai.stanford.edu/~nilsson/OnlinePubs-Nils/General Essays/AIMag04-04-002.pdf), *AI Magazine* **1** (1), Presidential Address to the Association for the Advancement of Artificial Intelligence.

- Penrose, Roger (1989). *The Emperor's New Mind: Concerning Computer, Minds and The Laws of Physics*. Oxford University Press. ISBN 0-19-851973-7.
- Searle, John (1980). "Minds, Brains and Programs" (http://www.bbsonline.org/documents/a/00/00/04/84/bbs00000484-00/bbs.searle2.html). *Behavioral and Brain Sciences* **3** (3): 417–457. doi:10.1017/S0140525X00005756.
- Searle, John (1999). *Mind, language and society*. New York, NY: Basic Books. ISBN 0-465-04521-9. OCLC 231867665 43689264.
- Serenko, Alexander; Detlor, Brian (2004). "Intelligent agents as innovations" (http://foba.lakeheadu.ca/serenko/papers/Serenko_Detlor_AI_and_Society.pdf). *AI and Society* **18** (4): 364–381. doi:10.1007/s00146-004-0310-5.
- Serenko, Alexander; Ruhi, Umar; Cocosila, Mihail (2007). "Unplanned effects of intelligent agents on Internet use: Social Informatics approach" (http://foba.lakeheadu.ca/serenko/papers/AI_Society_Serenko_Social_Impacts_of_Agents.pdf). *AI and Society* **21** (1–2): 141–166. doi:10.1007/s00146-006-0051-8.
- Shapiro, Stuart C. (1992). "Artificial Intelligence" (http://www.cse.buffalo.edu/~shapiro/Papers/ai.pdf). In Shapiro, Stuart C.. *Encyclopedia of Artificial Intelligence* (2nd ed.). New York: John Wiley. pp. 54–57. ISBN 0-471-50306-1.
- Simon, H. A. (1965). *The Shape of Automation for Men and Management*. New York: Harper & Row.
- Skillings, Jonathan (3 July 2006). "Getting Machines to Think Like Us" (http://news.cnet.com/Getting-machines-to-think-like-us/2008-11394_3-6090207.html). *cnet*. Retrieved 3 February 2011.
- Tecuci, Gheorghe (March/April 2012). "Artificial Intelligence". *Wiley Interdisciplinary Reviews: Computational Statistics* (Wiley) **4** (2): 168–180. doi:10.1002/wics.200.
- Turing, Alan (October 1950), "Computing Machinery and Intelligence" (http://loebner.net/Prizef/TuringArticle.html), *Mind* **LIX** (236): 433–460, doi:10.1093/mind/LIX.236.433, ISSN 0026-4423, retrieved 2008-08-18.
- van der Walt, Christiaan; Bernard, Etienne (2006<!—year is presumed based on acknowledgements at the end of the article—>). "Data characteristics that determine classifier performance" (http://www.patternrecognition.co.za/publications/cvdwalt_data_characteristics_classifiers.pdf) (PDF). Retrieved 5 August 2009.
- Vinge, Vernor (1993). "The Coming Technological Singularity: How to Survive in the Post-Human Era" (http://www-rohan.sdsu.edu/faculty/vinge/misc/singularity.html).
- Wason, P. C.; Shapiro, D. (1966). "Reasoning". In Foss, B. M.. *New horizons in psychology*. Harmondsworth: Penguin.
- Weizenbaum, Joseph (1976). *Computer Power and Human Reason*. San Francisco: W.H. Freeman & Company. ISBN 0-7167-0464-1.

Further reading

- TechCast Article Series, John Sagi, Framing Consciousness (http://www.techcast.org/Upload/PDFs/634146249446122137_Consciousness-Sagifinalversion.pdf)
- Boden, Margaret, Mind As Machine, Oxford University Press, 2006
- Johnston, John (2008) "The Allure of Machinic Life: Cybernetics, Artificial Life, and the New AI", MIT Press
- Myers, Courtney Boyd ed. (2009). The AI Report (http://www.forbes.com/2009/06/22/singularity-robots-computers-opinions-contributors-artificial-intelligence-09_land.html). Forbes June 2009
- Serenko, Alexander (2010). "The development of an AI journal ranking based on the revealed preference approach" (http://foba.lakeheadu.ca/serenko/papers/JOI_Serenko_AI_Journal_Ranking_Published.pdf) (PDF). *Journal of Informetrics* **4** (4): 447–459. doi:10.1016/j.joi.2010.04.001.
- Sun, R. & Bookman, L. (eds.), *Computational Architectures: Integrating Neural and Symbolic Processes*. Kluwer Academic Publishers, Needham, MA. 1994.

External links

- What Is AI? (http://www-formal.stanford.edu/jmc/whatisai/whatisai.html) — An introduction to artificial intelligence by AI founder John McCarthy.
- **Logic and Artificial Intelligence** (http://plato.stanford.edu/entries/logic-ai) entry by Richmond Thomason in the ***Stanford Encyclopedia of Philosophy***
- AI (http://www.dmoz.org/Computers/Artificial_Intelligence//) at the Open Directory Project
- AITopics (http://aaai.org/AITopics/) — A large directory of links and other resources maintained by the Association for the Advancement of Artificial Intelligence, the leading organization of academic AI researchers.
- Artificial Intelligence Discussion group (https://www.researchgate.net/group/Artificial_Intelligence)

Outline of artificial intelligence

The following outline is provided as an overview of and topical guide to artificial intelligence:

Artificial intelligence (AI) – branch of computer science that deals with intelligent behavior, learning, and adaptation *in machines*. Research in AI is concerned with producing machines to automate tasks requiring intelligent behavior.

Branches of artificial intelligence

- Symbolic
  - Good Old Fashioned AI –
- Sub-symbolic
  - Early cybernetics and brain simulation
  - Behavior based AI
    - Subsumption architecture
  - Nouvelle AI
  - Computational intelligence (CI)
    - Computational creativity –
    - Neural networks –
      - Hybrid neural network –
      - Recurrent neural network –
    - Fuzzy systems –
    - Evolutionary computation, including:
      - Evolutionary algorithms –
        - Genetic algorithm –
      - Brain Emotional Learning Based Intelligent Controller
      - Swarm intelligence –
        - Ant colony optimization –
- Statistical AI

Some applications of artificial intelligence

- Artificial Creativity
- Artificial life
- Automated planning and scheduling –
- Automated reasoning
- Automation
- Automatic target recognition –
- Biologically inspired computing
- Computer Audition –
    - Speech recognition
    - Speaker recognition
- Computer vision
    - Image processing
    - Intelligent word recognition –
    - Object recognition
    - Optical mark recognition
        - Handwriting recognition
        - Optical character recognition
            - Automatic number plate recognition
    - Facial recognition systems
        - Silent speech interface
- Diagnosis (artificial intelligence)
- Expert system –
    - Decision support system –
        - Clinical decision support system
- Game artificial intelligence
    - Computer game bot
    - Video game AI
        - Computer chess
        - Computer Go
    - General Game Playing
    - Game theory
- Hybrid intelligent system
- Intelligent agent
    - Agent architecture
        - Cognitive architecture
- Intelligent control
- Knowledge management
    - Concept mining
        - Data mining
        - Text mining
    - E-mail spam filtering
    - Information extraction
        - Activity recognition

        - Image retrieval
            - Automatic image annotation
        - Named-entity extraction
            - Coreference resolution
            - Named-entity recognition
            - Relationship extraction
            - Terminology extraction
    - Knowledge representation
    - Semantic Web
- Machine learning
    - Constrained Conditional Models –
    - Neural modeling fields –
- Natural language processing
    - Chatterbots
    - Language identification
    - Natural language user interface
    - Natural language understanding –
    - Machine translation
        - Statistical semantics
    - Question answering
    - Semantic translation
- Nonlinear control
- Pattern recognition
    - Optical character recognition
    - Handwriting recognition
    - Speech recognition
    - Face recognition
- Robotics
    - Behavior-based robotics
    - Cognitive
    - Cybernetics
    - Developmental robotics
    - Epigenetic robotics
    - Evolutionary robotics
- Speech generating device
- Strategic planning
- Vehicle infrastructure integration
- Virtual Intelligence –
- Virtual reality

Philosophy of artificial intelligence

Philosophy of artificial intelligence

- Artificial brain –
- Philosophical views of artificial consciousness –
  - User illusion –
- Artificial intelligence and law –
- Chinese room –
- Cognitive science
  - Artificial consciousness
  - Embodied cognitive science
    - Embodied cognition –
- Ethics of artificial intelligence –
- Philosophy of the Mind –
  - Computational theory of mind –
  - Functionalism –
- Physical symbol system –
- Synthetic intelligence –
- Turing Test –

History of artificial intelligence

Main article: History of artificial intelligence

- Progress in artificial intelligence
- Timeline of artificial intelligence
- AI effect
- AI winter

Artificial intelligence in fiction

Main article: Artificial intelligence in fiction

- Angel F (2007) –
- The Matrix (1999)
- The Terminator (1984)

Artificial intelligence and the future

- Seed AI –
- Singularitarianism
- Strong AI –
- Technological singularity

Psychology and AI

- Artificial psychology
- AI effect
- Uncanny valley

Concepts in artificial intelligence

- Action selection –
- Affective computing –
- AI box –
- AI-complete –
- Algorithmic probability –
- Automated reasoning –
- Autonomic Computing –
- Autonomic Networking –
- Backward chaining –
- Bayesian network –
- Bio-inspired computing –
  - Artificial immune systems –
- Blackboard system –
- Chatterbot –
- Combs method –
- Commonsense reasoning –
- Computational humor –
- Computer-assisted proof –
- Conceptual dependency theory –
- Darwin machine –
- Description logic –
- Frame problem –
- Game theory –
- Grammar systems theory –
- Informatics (academic field) –
- Intelligent control –
- Kinect –
- LIDA (cognitive architecture) –
- Means-ends analysis –
- Moravec's paradox –
- Music and artificial intelligence –
- Ordered weighted averaging aggregation operator –
- PEAS – Performance, Environment, Actuators, Sensors
- Percept (artificial intelligence) –
- Perceptual Computing –
- Rule-based system –
- Self-management (computer science) –
- Soft computing –
- Software agent –
  - Intelligent agent / Rational agent –

    - Autonomous agent –
    - Automated planning and scheduling
    - Control system
      - Hierarchical control system
      - Networked control system
    - Distributed artificial intelligence –
    - Multi-agent system –
    - Monitoring and Surveillance Agents
  - Embodied agent –
  - Situated AI
- Sussman Anomaly –
- Wetware (brain) –

AI projects

- Automated Mathematician (1977) –
- Allen (robot) (late 1980s) –
- Open Mind Common Sense (1999 -) –
- Mindpixel (2000–2005) –
- Cognitive Assistant that Learns and Organizes (2003–2008) –
- Watson (2011) –
  - Purpose: Open domain question answering
  - Technologies employed:
    - Natural Language Processing
    - Information Retrieval
    - Knowledge Representation
    - Automated reasoning
    - Machine Learning

Notable AI software

- OpenAIR –
- OpenCog –
- OpenIRIS –
- RapidMiner –

Competitions and awards

- Loebner Prize –

Publications

- *Adaptive Behavior (journal)* –
- *AI Memo* –
- *Artificial Intelligence: A Modern Approach* –
- *Artificial Minds* –
- *Computational Intelligence* –
- *Computing Machinery and Intelligence* –
- *Electronic Transactions on Artificial Intelligence* –
- *IEEE Intelligent Systems* –
- *IEEE Transactions on Pattern Analysis and Machine Intelligence* –
- *Neural Networks (journal)* –
- *On Intelligence* –
- *Paradigms of AI Programming: Case Studies in Common Lisp* –
- *What Computers Can't Do*

Organizations

- Artificial General Intelligence Research Institute
- Artificial Intelligence and Robotics Society
- Artificial Intelligence Applications Institute
- Association for the Advancement of Artificial Intelligence
- European Coordinating Committee for Artificial Intelligence
- European Neural Network Society
- ILabs
- International Joint Conferences on Artificial Intelligence
- Knowledge Engineering and Machine Learning Group
- Society for the Study of Artificial Intelligence and the Simulation of Behaviour

Companies

- Consolidated Robotics –
- Universal Robotics –

Artificial intelligence researchers and scholars

1930s and 40s (generation 0)

Alan Turing, John Von Neumann, Norbert Wiener, Claude Shannon, Nathaniel Rochester, Walter Pitts, Warren McCullough

1950s (the founders)

John McCarthy, Marvin Minsky, Allen Newell and Herbert A. Simon

1960s (their students)

- Edward Feigenbaum
- Raj Reddy
- Seymour Papert
- Ray Solomonoff

1970s

- Douglas Hofstadter

1980s

Judea Pearl, Rodney Brooks

More recent scholars

Hugo de Garis

External links

- AI [1] at the Open Directory Project
- Artificial Intelligence Directory, a directory of Web resources related to artificial intelligence [2]
- The Association for the Advancement of Artificial Intelligence [3]
- Freeview Video 'Machines with Minds' by the Vega Science Trust and the BBC/OU [4]
- John McCarthy's frequently asked questions about AI [5]
- Jonathan Edwards looks at AI (BBC audio) [6] C
- Ray Kurzweil's website dedicated to AI including prediction of future development in AI [7]
- **Logic and Artificial Intelligence** [8] entry by Richmond Thomason in the ***Stanford Encyclopedia of Philosophy***

References

[1] http://www.dmoz.org/Computers/Artificial_Intelligence//
[2] http://www.ai-directory.com
[3] http://www.aaai.org/AITopics/html/welcome.html
[4] http://www.vega.org.uk/video/programme/16
[5] http://www-formal.stanford.edu/jmc/whatisai/whatisai.html
[6] http://www.aiai.ed.ac.uk/events/jonathanedwards2007/bbc-r4-jonathan-edwards-2007-03-28.mp3
[7] http://www.kurzweilai.net/
[8] http://plato.stanford.edu/entries/logic-ai

AI-complete

In the field of artificial intelligence, the most difficult problems are informally known as **AI-complete** or **AI-hard**, implying that the difficulty of these computational problems is equivalent to solving the central artificial intelligence problem—making computers as intelligent as people, or strong AI.[1] To call a problem AI-complete reflects an attitude that it would not be solved by a simple specific algorithm.

AI-complete problems are hypothesised to include computer vision, natural language understanding, and dealing with unexpected circumstances while solving any real world problem.[2]

With current technology, AI-complete problems cannot be solved by computer alone, but also require human computation. This property can be useful, for instance to test for the presence of humans as with CAPTCHAs, and for computer security to circumvent brute-force attacks.[3][4]

History

The term was coined by Fanya Montalvo by analogy with NP-complete and NP-hard in complexity theory, which formally describes the most famous class of difficult problems.[5] Early uses of the term are in Erik Mueller's 1987 Ph.D. dissertation[6] and in Eric Raymond's 1991 Jargon File.[7]

AI-complete problems

AI-complete problems are hypothesised to include:

- Computer vision (and subproblems such as object recognition)
- Natural language understanding (and subproblems such as text mining, machine translation, and word sense disambiguation)
- Dealing with unexpected circumstances while solving any real world problem, whether it's navigation or planning or even the kind of reasoning done by expert systems.

Machine translation

To translate accurately, a machine must be able to understand the text. It must be able to follow the author's argument, so it must have some ability to reason. It must have extensive world knowledge so that it knows what is being discussed — it must at least be familiar with all the same commonsense facts that the average human translator knows. Some of this knowledge is in the form of facts that can be explicitly represented, but some knowledge is unconscious and closely tied to the human body: for example, the machine may need to understand how an ocean makes one *feel* to accurately translate a specific metaphor in the text. It must also model the authors' goals, intentions, and emotional states to accurately reproduce them in a new language. In short, the machine is required to have wide variety of human intellectual skills, including reason, commonsense knowledge and the intuitions that underlie motion and manipulation, perception, and social intelligence. Machine translation, therefore, is believed to be AI-complete: it may require strong AI to be done as well as humans can do it.

Software brittleness

AI systems can solve very simple restricted versions of AI-complete problems, but never in their full generality. When AI researchers attempt to "scale up" their systems to handle more complicated, real world situations, the programs tend to become excessively brittle without commonsense knowledge or a rudimentary understanding of the situation: they fail as unexpected circumstances outside of its original problem context begin to appear. When human beings are dealing with new situations in the world, they are helped immensely by the fact that they know what to expect: they know what all things around them are, why they are there, what they are likely to do and so on. They

can recognize unusual situations and adjust accordingly. A machine without strong AI has no other skills to fall back on.[8]

Formalization

Computational complexity theory deals with the relative computational difficulty of computable functions. By definition it does not cover problems whose solution are unknown or have not been characterised formally. Since many AI problems have no formalisation yet, conventional complexity theory does not allow the definition of AI-completeness.

To address this problem, a complexity theory for AI has been proposed.[9] It is based on a model of computation that splits the computational burden between a computer and a human: one part is solved by computer and the other part solved by human. This is formalised by a **human-assisted Turing machine**. The formalisation defines algorithm complexity, problem complexity and reducibility which in turn allows equivalence classes to be defined.

The complexity of executing an algorithm with a human-assisted Turing machine is given by a pair $\langle \Phi_H, \Phi_M \rangle$, where the first element represents the complexity of the human's part and the second element is the complexity of the machine's part.

Results

The complexity of solving the following problems with a human-assisted Turing machine is:[9]

- Optical character recognition for printed text: $\langle O(1), poly(n) \rangle$
- Turing test:
  - for an n -sentence conversation where the oracle remembers the conversation history (persistent oracle): $\langle O(n), O(n) \rangle$
  - for an n -sentence conversation where the conversation history must be retransmitted: $\langle O(n), O(n^2) \rangle$
  - for an n -sentence conversation where the conversation history must be retransmitted and the person takes linear time to read the query $\langle O(n^2), O(n^2) \rangle$
- ESP game: $\langle O(n), O(n) \rangle$
- Image labelling (based on the Arthur–Merlin protocol): $\langle O(n), O(n) \rangle$
- Image classification: human only: $\langle O(n), O(n) \rangle$, and with less reliance on the human: $\langle O(\log n), O(n \log n) \rangle$.

References

[1] Shapiro, Stuart C. (1992). Artificial Intelligence (http://www.cse.buffalo.edu/~shapiro/Papers/ai.pdf) In Stuart C. Shapiro (Ed.), *Encyclopedia of Artificial Intelligence* (Second Edition, pp. 54–57). New York: John Wiley. (Section 4 is on "AI-Complete Tasks".)

[2] Roman V. Yampolskiy. Turing Test as a Defining Feature of AI-Completeness . In Artificial Intelligence, Evolutionary Computation and Metaheuristics (AIECM) --In the footsteps of Alan Turing. Xin-She Yang (Ed.). pp. 3-17. (Chapter 1). Springer, London. 2013. http://cecs.louisville.edu/ry/TuringTestasaDefiningFeature04270003.pdf

[3] Luis von Ahn, Manuel Blum, Nicholas Hopper, and John Langford. CAPTCHA: Using Hard AI Problems for Security (http://www.captcha.net/captcha_crypt.pdf). In Proceedings of Eurocrypt, Vol. 2656 (2003), pp. 294-311.

[4] Bergmair, Richard (January 7, 2006). *Natural Language Steganography and an "AI-complete" Security Primitive*. CiteSeerX: 10.1.1.105.129 (http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.105.129). (unpublished?)

[5] Mallery, John C. (1988), "Thinking About Foreign Policy: Finding an Appropriate Role for Artificially Intelligent Computers" (http://citeseer.ist.psu.edu/mallery88thinking.html), *The 1988 Annual Meeting of the International Studies Association.*, St. Louis, MO, .

[6] Mueller, Erik T. (1987, March). *Daydreaming and Computation* (Technical Report CSD-870017) (ftp://ftp.cs.ucla.edu/tech-report/198_-reports/870017.pdf) Ph.D. dissertation, University of California, Los Angeles. ("Daydreaming is but one more *AI-complete* problem: if we could solve any one artificial intelligence problem, we could solve all the others", p. 302)

[7] Raymond, Eric S. (1991, March 22). Jargon File Version 2.8.1 (http://catb.org/esr/jargon/oldversions/jarg282.txt) (Definition of "AI-complete" first added to jargon file.)

[8] Lenat, Douglas; Guha, R. V. (1989), *Building Large Knowledge-Based Systems*, Addison-Wesley, pp. 1–5

[9] Dafna Shahaf and Eyal Amir (2007) Towards a theory of AI completeness (http://www.cs.uiuc.edu/~eyal/papers/ai-complete-commonsense07.pdf). Commonsense 2007, 8th International Symposium on Logical Formalizations of Commonsense Reasoning (http://www.ucl.ac.uk/commonsense07).

Strong AI

For John Searle's Strong AI hypothesis, see Philosophy of artificial intelligence

Strong AI is artificial intelligence that matches or exceeds human intelligence — the intelligence of a machine that can successfully perform any intellectual task that a human being can.[1] It is a primary goal of artificial intelligence research and an important topic for science fiction writers and futurists. Strong AI is also referred to as "**artificial general intelligence**"[2] or as the ability to perform "general intelligent action."[3] Strong AI is associated with traits such as consciousness, sentience, sapience and self-awareness observed in living beings.

Some references emphasize a distinction between strong AI and "applied AI"[4] (also called "narrow AI"[1] or "weak AI"[5]): the use of software to study or accomplish specific problem solving or reasoning tasks. Weak AI, in contrast to strong AI, does not attempt to simulate the full range of human cognitive abilities.

Requirements

Many different definitions of intelligence have been proposed (such as being able to pass the Turing test) but there is to date no definition that satisfies everyone.[6] However, there *is* wide agreement among artificial intelligence researchers that intelligence is required to do the following:[7]

- reason, use strategy, solve puzzles, and make judgments under uncertainty;
- represent knowledge, including commonsense knowledge;
- plan;
- learn;
- communicate in natural language;
- and integrate all these skills towards common goals.

Other important capabilities include the ability to sense (e.g. see) and the ability to act (e.g. move and manipulate objects) in the world where intelligent behaviour is to be observed.[8] This would include an ability to detect and respond to hazard.[9] Some sources consider "salience" (the capacity for recognising importance) as an important trait. Salience is thought to be part of how humans evaluate novelty so are likely to be important in some degree, but not necessarily at a human level. Many interdisciplinary approaches to intelligence (e.g. cognitive science, computational intelligence and decision making) tend to emphasise the need to consider additional traits such as imagination (taken as the ability to form mental images and concepts that were not programmed in)[10] and autonomy.[11] Computer based systems that exhibit many of these capabilities do exist (e.g. see computational creativity, decision support system, robot, evolutionary computation, intelligent agent), but not yet at human levels.

There are other aspects of the human mind besides intelligence that are relevant to the concept of strong AI which play a major role in science fiction and the ethics of artificial intelligence:

- consciousness: To have subjective experience and thought.[12]
- self-awareness: To be aware of oneself as a separate individual, especially to be aware of one's own thoughts.
- sentience: The ability to "feel" perceptions or emotions subjectively.
- sapience: The capacity for wisdom.

These traits have a moral dimension, because a machine with this form of strong AI may have legal rights, analogous to the rights of animals. Also, Bill Joy, among others, argues a machine with these traits may be a threat to human life or dignity.[13] It remains to be shown whether any of these traits are necessary for strong AI. The role of consciousness is not clear, and currently there is no agreed test for its presence. If a machine is built with a device

that simulates the neural correlates of consciousness, would it automatically have self-awareness? It is also possible that some of these properties, such as sentience, naturally emerge from a fully intelligent machine, or that it becomes natural to *ascribe* these properties to machines once they begin to act in a way that is clearly intelligent. For example, intelligent action may be sufficient for sentience, rather than the other way around.

Mainstream AI research

History of mainstream research into strong AI

Modern AI research began in the mid 1950s.[14] The first generation of AI researchers were convinced that strong AI was possible and that it would exist in just a few decades. As AI pioneer Herbert A. Simon wrote in 1965: "machines will be capable, within twenty years, of doing any work a man can do."[15] Their predictions were the inspiration for Stanley Kubrick and Arthur C. Clarke's character HAL 9000, who accurately embodied what AI researchers believed they could create by the year 2001. Of note is the fact that AI pioneer Marvin Minsky was a consultant[16] on the project of making HAL 9000 as realistic as possible according to the consensus predictions of the time; Crevier quotes him as having said on the subject in 1967, "Within a generation...the problem of creating 'artificial intelligence' will substantially be solved,",[17] although Minsky states that he was misquoted.

However, in the early 1970s, it became obvious that researchers had grossly underestimated the difficulty of the project. The agencies that funded AI became skeptical of strong AI and put researchers under increasing pressure to produce useful technology, or "applied AI".[18] As the 1980s began, Japan's fifth generation computer project revived interest in strong AI, setting out a ten year timeline that included strong AI goals like "carry on a casual conversation".[19] In response to this and the success of expert systems, both industry and government pumped money back into the field.[20] However, the market for AI spectacularly collapsed in the late 1980s and the goals of the fifth generation computer project were never fulfilled.[21] For the second time in 20 years, AI researchers who had predicted the imminent arrival of strong AI had been shown to be fundamentally mistaken about what they could accomplish. By the 1990s, AI researchers had gained a reputation for making promises they could not keep. AI researchers became reluctant to make any kind of prediction at all[22] and avoid any mention of "human level" artificial intelligence, for fear of being labeled a "wild-eyed dreamer."[23]

Current mainstream AI research

In the 1990s and early 21st century, mainstream AI has achieved a far higher degree of commercial success and academic respectability by focusing on specific sub-problems where they can produce verifiable results and commercial applications, such as neural nets, computer vision or data mining.[24] These "applied AI" applications are now used extensively throughout the technology industry and research in this vein is very heavily funded in both academia and industry.

Most mainstream AI researchers hope that strong AI can be developed by combining the programs that solve various subproblems using an integrated agent architecture, cognitive architecture or subsumption architecture. Hans Moravec wrote in 1988 "I am confident that this bottom-up route to artificial intelligence will one day meet the traditional top-down route more than half way, ready to provide the real world competence and the commonsense knowledge that has been so frustratingly elusive in reasoning programs. Fully intelligent machines will result when the metaphorical golden spike is driven uniting the two efforts."[25] However, it should be noted that much contention has existed in AI research, even with regards to the fundamental philosophies informing this field; for example, Harnad, S. from Princeton stated in the conclusion of his 1990 paper on the Symbol Grounding Hypothesis that "The expectation has often been voiced that "top-down" (symbolic) approaches to modeling cognition will somehow meet "bottom-up" (sensory) approaches somewhere in between. If the grounding considerations in this paper are valid, then this expectation is hopelessly modular and there is really only one viable route from sense to symbols: from the ground up. A free-floating symbolic level like the software level of a computer will never be

reached by this route (or vice versa) -- nor is it clear why we should even try to reach such a level, since it looks as if getting there would just amount to uprooting our symbols from their intrinsic meanings (thereby merely reducing ourselves to the functional equivalent of a programmable computer)."[26]

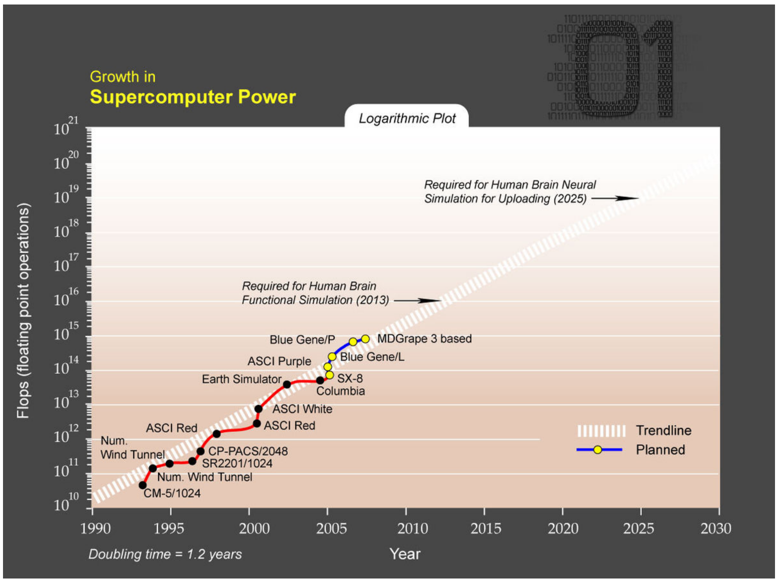
Artificial General Intelligence research

Artificial General Intelligence[27] (AGI) describes research that aims to create machines capable of general intelligent action. The term was introduced by Mark Gubrud in 1997[28] in a discussion of the implications of fully automated military production and operations. The research objective is much older, for example Doug Lenat's Cyc project (that began in 1984), and Allen Newell's Soar project are regarded as within the scope of AGI. AGI research activity in 2006 was described by Pei Wang and Ben Goertzel[29] as "producing publications and preliminary results". As yet, most AI researchers have devoted little attention to AGI, with some claiming that intelligence is too complex to be completely replicated in the near term. However, a small number of computer scientists are active in AGI research, and many of this group are contributing to a series of AGI conferences. The research is extremely diverse and often pioneering in nature. In the introduction to his book,[27] Goertzel says that estimates of the time needed before a truly flexible AGI is built vary from 10 years to over a century, but the consensus in the AGI research community seems to be that the timeline discussed by Ray Kurzweil in "The Singularity is Near"[1] (i.e. between 2015 and 2045) is plausible.[30] Most mainstream AI researchers doubt that progress will be this rapid. Organizations actively pursuing AGI include Adaptive AI, Artificial General Intelligence Research Institute (AGIRI), the Singularity Institute for Artificial Intelligence, Bitphase AI [31], and TexAI.[32] One recent addition is Numenta, a project based on the theories of Jeff Hawkins, the creator of the Palm Pilot. While Numenta takes a computational approach to general intelligence, Hawkins is also the founder of the Redwood Neuroscience Institute, which explores conscious thought from a biological perspective. AND Corporation has been active in this field since 1990, and has developed machine intelligence processes based on phase coherence principles,[33] having strong similarities to digital holography and QM with respect to quantum collapse of the wave function. Ben Goertzel is pursuing an embodied AGI through the open-source OpenCog project. Current code includes embodied virtual pets capable of learning simple English-language commands, as well as integration with real-world robotics, being done at the robotics lab of Hugo de Garis at Xiamen University.

Whole brain emulation

A popular approach discussed to achieving general intelligent action is whole brain emulation. A low-level brain model is built by scanning and mapping a biological brain in detail and copying its state into a computer system or another computational device. The computer runs a simulation model so faithful to the original that it will behave in essentially the same way as the original brain, or for all practical purposes, indistinguishably.[34] Whole brain emulation is discussed in computational neuroscience and neuroinformatics, in the context of brain simulation for medical research purposes. It is discussed in artificial intelligence research[30] as an approach to strong AI. Neuroimaging technologies, that could deliver the necessary detailed understanding, are improving rapidly, and futurist Ray Kurzweil in the book *The Singularity Is Near*[1] predicts that a map of sufficient quality will become available on a similar timescale to the required computing power.

Processing requirements



Futurist Ray Kurzweil's projected supercomputer processing power

For low-level brain simulation, an extremely powerful computer would be required. The human brain has a huge number of synapses. Each of the 10^{11} (one hundred billion) neurons has on average 7,000 synaptic connections to other neurons. It has been estimated that the brain of a three-year-old child has about 10^{15} synapses (1 quadrillion). This number declines with age, stabilizing by adulthood. Estimates vary for an adult, ranging from 10^{14} to 5 x 10^{14} synapses (100 to 500 trillion).[35] An estimate of the brain's processing power, based on a simple switch model for neuron activity, is around 10^{14} (100 trillion) neuron updates per second.[36] Kurzweil looks at various estimates for the hardware required to equal the human brain and adopts a figure of 10^{16} computations per second (cps).[37] He uses this figure to predict the necessary hardware will be available sometime between 2015 and 2025, if the current exponential growth in computer power continues.

Complications

A fundamental criticism of the simulated brain approach derives from embodied cognition where human embodiment is taken as an essential aspect of human intelligence. Many researchers believe that embodiment is necessary to ground meaning.[38] If this view is correct, any fully functional brain model will need to encompass more than just the neurons (i.e., a robotic body). Goertzel[30] proposes virtual embodiment (like Second Life), but it is not yet known whether this would be sufficient.

Desktop computers using 2 GHz Intel Pentium microprocessors and capable of more than 10^9 cps have been available since 2005. According to the brain power estimates used by Kurzweil (and Moravec), this computer should be capable of supporting a simulation of a bee brain, but despite some interest[39] no such simulation exists . There are at least three reasons for this.

- Firstly, the neuron model seems to be oversimplified (see next section).
- Secondly, there is insufficient understanding of higher cognitive processes[40] to establish accurately what the neural activity observed using techniques, such as functional magnetic resonance imaging correlates with.
- Thirdly, even if our understanding of cognition advances sufficiently, early simulation programs are likely to be very inefficient and will, therefore, need considerably more hardware.

In addition, the scale of the human brain is not currently well-constrained. One estimate puts the human brain at about 100 billion neurons and 100 trillion synapses.[41][42] Another estimate is 86 billion neurons of which 16.3 billion are in the cerebral cortex and 69 billion in the cerebellum.[43] Glial cell synapses are currently unquantified but are known to be extremely numerous.

Modelling the neurons in more detail

The artificial neuron model assumed by Kurzweil and used in many current artificial neural network implementations is simple compared with biological neurons. A brain simulation would likely have to capture the detailed cellular behaviour of biological neurons, presently only understood in the broadest of outlines. The overhead introduced by full modeling of the biological, chemical, and physical details of neural behaviour (especially on a molecular scale) would require a computer several orders of magnitude larger than Kurzweil's estimate. In addition the estimates do not account for Glial cells which are at least as numerous as neurons, may outnumber neurons by as much as 10:1, and are now known to play a role in cognitive processes.

There are some research projects that are investigating brain simulation using more sophisticated neural models, implemented on conventional computing architectures. The Artificial Intelligence System project implemented non-real time simulations of a "brain" (with 10^{11} neurons) in 2005. It took 50 days on a cluster of 27 processors to simulate 1 second of a model.[44] The Blue Brain project used one of the fastest supercomputer architectures in the world, IBM's Blue Gene platform, to create a real time simulation of a single rat neocortical column consisting of approximately 10,000 neurons and 10^8 synapses in 2006.[45] A longer term goal is to build a detailed, functional simulation of the physiological processes in the human brain: "It is not impossible to build a human brain and we can do it in 10 years," Henry Markram, director of the Blue Brain Project said in 2009 at the TED conference in Oxford.[46] There have also been controversial claims to have simulated a cat brain. Neuro-silicon interfaces have been proposed as an alternative implementation strategy that may scale better.[47]

Hans Moravec addressed the above arguments ("brains are more complicated", "neurons have to be modeled in more detail") in his 1997 paper "When will computer hardware match the human brain?".[48] He measured the ability of existing software to simulate the functionality of neural tissue, specifically the retina. His results do not depend on the number of glial cells, nor on what kinds of processing neurons perform where.

Artificial consciousness research

Although the role of consciousness in strong AI/AGI is debatable, many AGI researchers[49] regard research that investigates possibilities for implementing consciousness as vital. In an early effort Igor Aleksander[50] argued that the principles for creating a conscious machine already existed but that it would take forty years to train such a machine to understand language.

Origin of the term: John Searle's strong AI

The term "strong AI" was adopted from the name of a position in the philosophy of artificial intelligence first identified by John Searle as part of his Chinese room argument in 1980.[51] He wanted to distinguish between two different hypotheses about artificial intelligence:[52]

- An artificial intelligence system can *think* and have a *mind*. (The word "mind" has a specific meaning for philosophers, as used in "the mind body problem" or "the philosophy of mind".)
- An artificial intelligence system can (only) *act like* it thinks and has a mind.

The first one is called "the *strong* AI hypothesis" and the second is "the *weak* AI hypothesis" because the first one makes the *stronger* statement: it assumes something special has happened to the machine that goes beyond all its abilities that we can test. Searle referred to the "strong AI hypothesis" as "strong AI". This usage, which is fundamentally different than the subject of this article, is common in academic AI research and textbooks.[53]

The term "strong AI" is now used to describe any artificial intelligence system that acts like it has a mind,[1] regardless of whether a philosopher would be able to determine if it *actually* has a mind or not. As Russell and Norvig write: "Most AI researchers take the weak AI hypothesis for granted, and don't care about the strong AI hypothesis."[54] AI researchers *are* interested in a related statement:

- An artificial intelligence system can think (*or* act like it thinks) *as well as or better than people do*.

This assertion, which hinges on the breadth and power of machine intelligence, *is* the subject of this article.

Possible explanations for the slow progress of AI research

See also The problems (in History of AI)

Since the launch of AI research in 1956, the growth of this field has slowed down over time and has stalled the aims of creating machines skilled with intelligent action at the human level.[55] A possible explanation for this delay is that computers lack a sufficient scope of memory or processing power.[55] In addition, the level of complexity that connects to the process of AI research may also limit the progress of AI research.[55]

While most AI researchers believe that strong AI can be achieved in the future, there are some individuals like Hubert Dreyfus and Roger Penrose that deny the possibility of achieving AI.[55] John McCarthy was one of various computer scientists who believe human-level AI will be accomplished, but a date cannot accurately be predicted.[56]

Conceptual limitations are another possible reason for the slowness in AI research.[55] AI researchers may need to modify the conceptual framework of their discipline in order to provide a stronger base and contribution to the quest of achieving strong AI. As William Clocksin wrote in 2003: "the framework starts from Weizenbaum’s observation that intelligence manifests itself only relative to specific social and cultural contexts".[55]

Furthermore, AI researchers have been able to create computers that can perform jobs that are complicated for people to do, but conversely they have struggled to develop a computer that is capable of carrying out tasks that are simple for humans to do.[55] A problem that is described by David Gelernter is that some people assume that thinking and reasoning are equivalent.[57] However, the idea of whether thoughts and the creator of those thoughts are isolated individually has intrigued AI researchers.[57]

The problems that have been encountered in AI research over the past decades have further impeded the progress of AI. The failed predictions that have been promised by AI researchers and the lack of a complete understanding of human behaviors have helped diminish the primary idea of human-level AI.[30] Although the progress of AI research has brought both improvement and disappointment, most investigators have established optimism about potentially achieving the goal of AI in the 21st century.[30]

Other possible reasons have been proposed for the lengthy research in the progress of strong AI. The intricacy of scientific problems and the need to fully understand the human brain through psychology and neurophysiology have limited many researchers from emulating the function of the human brain into a computer hardware.[58] Many researchers tend to underestimate any doubt that is involved with future predictions of AI, but without taking those issues seriously can people then overlook solutions to problematic questions.[30]

Clocksin says that a conceptual limitation that may impede the progress of AI research is that people may be using the wrong techniques for computer programs and implementation of equipment.[55] When AI researchers first began to aim for the goal of artificial intelligence, a main interest was human reasoning.[59] Researchers hoped to establish computational models of human knowledge through reasoning and to find out how to design a computer with a specific cognitive task.[59]

The practice of abstraction, which people tend to redefine when working with a particular context in research, provides researchers with a concentration on just a few concepts.[59] The most productive use of abstraction in AI research comes from planning and problem solving.[59] Although the aim is to increase the speed of a computation, the role of abstraction has posed questions about the involvement of abstraction operators.[60]

A possible reason for the slowness in AI relates to the acknowledgement by many AI researchers that heuristics is a section that contains a significant breach between computer performance and human performance.[58] The specific functions that are programmed to a computer may be able to account for many of the requirements that allow it to match human intelligence. These explanations are not necessarily guaranteed to be the fundamental causes for the delay in achieving strong AI, but they are widely agreed by numerous researchers.

There have been many AI researchers that debate over the idea whether machines should be created with emotions. There are no emotions in typical models of AI and some researchers say programming emotions into machines allows them to have a mind of their own.[55] Emotion sums up the experiences of humans because it allows them to remember those experiences.[57]

As David Gelernter writes, “No computer will be creative unless it can simulate all the nuances of human emotion.”[57] This concern about emotion has posed problems for AI researchers and it connects to the concept of strong AI as its research progresses into the future.

Criticism for Strong AI Research

If research into Stong AI ever produced software that was about as intelligent as man, then it may be able to reprogram and improve itself. The improved software would be even better at improving itself, leading to Recursive Self Improvement. It could thus become exponentially more intelligent than man.

Hyper intelligent software may not necessarily decide to support the continued existence of mankind, and would be extremely difficult to stop Yudkowsky, Eliezer (2008). This topic has also recently begun to be discussed in academic publications from the perspective of Risks to civilization, humans, and planet Earth.

One proposal to deal with this is to ensure that the first generally intelligent AI is 'Friendly AI', and will then be able to control subsequently developed AIs. However Berglas (2008) argues that is fundamentally against the principals of natural selection, and so is unlikely to be successful.

Notes

[1] (Kurzweil 2005, p. 260) or see Advanced Human Intelligence (http://crnano.typepad.com/crnblog/2005/08/advanced_human_.html) where he defines strong AI as "machine intelligence with the full range of human intelligence."

[2] Voss 2006

[3] Newell & Simon 1976. This the term they use for "human-level" intelligence in the physical symbol system hypothesis.

[4] Encyclopædia Britannica Strong AI, applied AI, and cognitive simulation (http://www.britannica.com/eb/article-219086/artificial-intelligence) or Jack Copeland What is artificial intelligence? (http://www.cs.usfca.edu/www.AlanTuring.net/turing_archive/pages/Reference Articles/what_is_AI/What is AI02.html) on AlanTuring.net

[5] The Open University on Strong and Weak AI (http://www.open2.net/nextbigthing/ai/ai_in_depth/in_depth.htm)

[6] AI founder John McCarthy writes: "we cannot yet characterize in general what kinds of computational procedures we want to call intelligent." [[John McCarthy McCarthy, John (2007). "Basic Questions" (http://www-formal.stanford.edu/jmc/whatisai/node1.html). Stanford University. . (For a discussion of some definitions of intelligence used by artificial intelligence researchers, see philosophy of artificial intelligence.)

[7] This list of intelligent traits is based on the topics covered by major AI textbooks, including: Russell & Norvig 2003, Luger & Stubblefield 2004, Poole, Mackworth & Goebel 1998 and Nilsson 1998.

[8] Pfeifer, R. and Bongard J. C., How the body shapes the way we think: a new view of intelligence (The MIT Press, 2007). ISBN 0-262-16239-3

[9] White, R. W. (1959). Motivation reconsidered: The concept of competence. Psychological Review, 66, 297-333

[10] Johnson 1987

[11] deCharms, R. (1968). Personal causation. New York: Academic Press.

[12] Note that consciousness is difficult to define. A popular definition, due to Thomas Nagel, is that it "feels like" something to be conscious. If we are not conscious, then it doesn't feel like anything. Nagel uses the example of a bat: we can sensibly ask "what does it feel like to be a bat?" However, we are unlikely to ask "what does it feel like to be a toaster?" Nagel concludes that a bat appears to be conscious (i.e. has consciousness) but a toaster does not. See (Nagel 1974)

[13] Joy, Bill (April 2000). "Why the future doesn't need us". *Wired*.

[14] Crevier 1993, pp. 48–50

[15] Simon 1965, p. 96 quoted in Crevier 1993, p. 109

[16] Scientist on the Set: An Interview with Marvin Minsky (http://mitpress.mit.edu/e-books/Hal/chap2/two1.html)

[17] Marvin Minsky to Darrach (1970), quoted in Crevier (1993, p. 109).

[18] The Lighthill report specifically criticized AI's "grandiose objectives" and led the dismantling of AI research in England. (Lighthill 1973; Howe 1994) In the U.S., DARPA became determined to fund only "mission-oriented direct research, rather than basic undirected research". See (NRC 1999) under "Shift to Applied Research Increases Investment". See also (Crevier 1993, pp. 115–117) and (Russell & Norvig 2003, pp. 21–22)

[19] Crevier 1993, pp. 211, Russell & Norvig 2003, p. 24 and see also Feigenbaum & McCorduck 1983

[20] Crevier 1993, pp. 161–162,197–203,240; Russell & Norvig 2003, p. 25; NRC 1999, under "Shift to Applied Research Increases Investment"

[21] Crevier 1993, pp. 209–212

[22] As AI founder John McCarthy writes "it would be a great relief to the rest of the workers in AI if the inventors of new general formalisms would express their hopes in a more guarded form than has sometimes been the case." McCarthy, John (2000). "Reply to Lighthill" (http://www-formal.stanford.edu/jmc/reviews/lighthill/lighthill.html). Stanford University. .

[23] "At its low point, some computer scientists and software engineers avoided the term artificial intelligence for fear of being viewed as wild-eyed dreamers."Markoff, John (2005-10-14). "Behind Artificial Intelligence, a Squadron of Bright Real People" (http://www.nytimes.com/2005/10/14/technology/14artificial.html?ei=5070&en=11ab55edb7cead5e&ex=1185940800&adxnnl=1&adxnnlx=1185805173-o7WsfW7qaP0x5/NUs1cQCQ). The New York Times. . Retrieved 2007-07-30.

[24] Russell & Norvig 2003, pp. 25–26

[25] Moravec 1988, p. 20

[26] Harnad, S. (1990) The Symbol Grounding Problem. Physica D 42: 335-346.

[27] Goertzel & Pennachin 2006

[28] Gubrud 1997

[29] Goertzel & Wang 2006. See also Wang (2006) with an up to date summary and lots of links.

[30] Goertzel 2007

[31] http://www.bitphase.com/

[32] The TexAI website (http://www.texai.org/blog/?page_id=44)

[33] Sutherland 1990

[34] Sanders 2008. "The basic idea is to take a particular brain, scan its structure in detail, and construct a software model of it that is so faithful to the original that, when run on appropriate hardware, it will behave in essentially the same way as the original brain."

[35] Drachman 2005

[36] Russell & Norvig 2003

[37] In "Mind Children" Moravec 1988, p. 61 10^{15} cps is used. More recently, in 1997, <http://www.transhumanist.com/volume1/moravec.htm> Moravec argued for 10^{8} MIPS which would roughly correspond to 10^{14} cps. Moravec talks in terms of MIPS, not "cps", which is a non-standard term Kurzweil introduced.

[38] de Vega, Glenberg & Graesser 2008. A wide range of views in current research, all of which require grounding to some degree

[39] some links to bee brain studies (http://www.setiai.com/archives/cat_honey_bee_brain.html)

[40] In this chapter (http://www.singinst.org/upload/LOGI//LOGI.pdf) of Goertzels AGI book Yudkowsky proposes 5 levels of organisation that must be understood - code/data, sensory modality, concept & category, thought and deliberation (consciousness) - in order to use the available hardware

[41] Williams & Herrup 1988

[42] "nervous system, human." (http://search.eb.com/eb/article-75525) *Encyclopædia Britannica*. 9 Jan. 2007

[43] Azevedo et al. 2009

[44] large scale model of brain (http://vesicle.nsi.edu/users/izhikevich/publications/large-scale_model_of_human_brain.pdf)

[45] "Project Milestones" (http://bluebrain.epfl.ch/Jahia/site/bluebrain/op/edit/pid/19085). *Blue Brain*. . Retrieved 2008-08-11.

[46] Artificial brain '10 years away' 2009 BBC news (http://news.bbc.co.uk/1/hi/technology/8164060.stm)

[47] University of Calgary news (http://gauntlet.ucalgary.ca/story/10343), MSNBC news (http://msnbc.msn.com/id/12037941/)

[48] http://www.transhumanist.com/volume1/moravec.htm

[49] Yudkowsky 2006

[50] Aleksander 1996

[51] Searle 1980

[52] As defined in a standard AI textbook: "The assertion that machines could possibly act intelligently (or, perhaps better, act as if they were intelligent) is called the 'weak AI' hypothesis by philosophers, and the assertion that machines that do so are actually thinking (as opposed to simulating thinking) is called the 'strong AI' hypothesis." (Russell & Norvig 2003)

[53] Among the many sources that use the term in this way are:

- Russell & Norvig 2003,
- Oxford University Press Dictionary of Psychology (http://www.encyclopedia.com/doc/1O87-strongAI.html) (quoted in "High Beam Encyclopedia"),
- MIT Encyclopedia of Cognitive Science (http://www.aaai.org/AITopics/html/phil.html) (quoted in "AITopics")
- Planet Math (http://planetmath.org/encyclopedia/StrongAIThesis.html)
- Arguments against Strong AI (http://www.cs.utexas.edu/~mooney/cs343/slide-handouts/philosophy.4.pdf) (Raymond J. Mooney, University of Texas),
- Artificial Intelligence (http://sern.ucalgary.ca/courses/CPSC/533/W99/intro/tsld024.htm) (Rob Kremer, University of Calgary),
- Minds, Math, and Machines: Penrose's thesis on consciousness (http://www.umanitoba.ca/faculties/science/mathematics/new/seminars/html/h24-85-203-153wpshawcablenetJan171420462003.html) (Rob Craigen, University of Manitoba),
- The Science and Philosophy of Consciousness (http://www.users.globalnet.co.uk/~lka/strongai.htm) Alex Green,
- Philosophy & AI (http://www.cs.waikato.ac.nz/~bernhard/316/slides/Chapter26_6pp.pdf) Bernard,

- Will Biological Computers Enable Artificially Intelligent Machines to Become Persons? (http://www.cbhd.org/resources/biotech/tongen_2003-11-07.htm) Anthony Tongen,
- Usenet FAQ on Strong AI (http://www.faqs.org/faqs/ai-faq/general/part1/section-4.html)

[54] Russell & Norvig 2003, p. 947
[55] Clocksin 2003
[56] McCarthy 2003
[57] Gelernter 2010
[58] McCarthy 2007
[59] Holte & Choueiry 2003
[60] Zucker 2003

References

- TechCast Article Series, Prof. William Halal, Automation of Thought (http://www.techcast.org/Upload/PDFs/633615794236495345_TCTheAutomationofThought.pdf)
- Aleksander, Igor (1996), *Impossible Minds*, World Scientific Publishing Company isbn=978-1-86094-036-1
- Anders, Sandberg; Nick, Boström (2008), *Whole Brain Emulation: A Roadmap* (http://www.fhi.ox.ac.uk/Reports/2008-3.pdf), Technical Report #2008-3, Future of Humanity Institute, Oxford University, retrieved 5 April 2009
- Azevedo FA, Carvalho LR, Grinberg LT, *et al.* (April 2009), "Equal numbers of neuronal and nonneuronal cells make the human brain an isometrically scaled-up primate brain", *The Journal of Comparative Neurology* **513** (5): 532–41, doi:10.1002/cne.21974, PMID 19226510
- Berglas, Anthony (2008), *Artificial Intelligence will Kill our Grandchildren* (http://berglas.org/Articles/AIKillGrandchildren/AIKillGrandchildren.html), retrieved 2008-06-13
- Chalmers, David (1996), *The Conscious Mind*, Oxford University Press.
- Clocksin, William (Aug 2003), "Artificial intelligence and the future", *Philosophical Transactions: Mathematical, Physical and Engineering Sciences* **361** (1809): 1721–1748, doi:10.1098/rsta.2003.1232, PMID 12952683.
- Crevier, Daniel (1993), *AI: The Tumultuous Search for Artificial Intelligence*, New York, NY: BasicBooks, ISBN 0-465-02997-3
- Darrach, Brad (20 November 1970), "Meet Shakey, the First Electronic Person", *Life Magazine*: 58–68.
- Drachman, D (2005), "Do we have brain to spare?", *Neurology* **64** (12): 2004–5, doi:10.1212/01.WNL.0000166914.38327.BB, PMID 15985565.
- Feigenbaum, Edward A.; McCorduck, Pamela (1983), *The Fifth Generation: Artificial Intelligence and Japan's Computer Challenge to the World*, Michael Joseph, ISBN 0-7181-2401-4
- Gelernter, David (2010), *Dream-logic, the Internet and Artificial Thought* (http://www.edge.org/3rd_culture/gelernter10.1/gelernter10.1_index.html), retrieved 25 July 2010
- Goertzel, Ben; Pennachin, Cassio, eds. (2006), *Artificial General Intelligence* (http://people.inf.elte.hu/csizsekp/ai/books/artificial-general-intelligence-cognitive-technologies.9783540237334.27156.pdf), Springer, ISBN 3-540-23733-X
- Goertzel, Ben; Wang, Pei (2006), *Introduction: Aspects of Artificial General Intelligence* (http://sites.google.com/site/narswang/publications/wang-goertzel.AGI_Aspects.pdf?attredirects=1)
- Goertzel, Ben (Dec 2007), "Human-level artificial general intelligence and the possibility of a technological singularity: a reaction to Ray Kurzweil's The Singularity Is Near, and McDermott's critique of Kurzweil" (http://scholar.google.com/scholar?hl=sv&lr=&cluster=15189798216526465792), *Artificial Intelligence* **171** (18, Special Review Issue): 1161–1173, doi:10.1016/j.artint.2007.10.011, retrieved 1 April 2009.
- Gubrud, Mark (November 1997), "Nanotechnology and International Security" (http://www.foresight.org/Conferences/MNT05/Papers/Gubrud/), *Fifth Foresight Conference on Molecular Nanotechnology*, retrieved 7 May 2011

- Holte, RC; Choueiry, BY (2003), "Abstraction and reformulation in artificial intelligence", *Philosophical Transactions: Biological Sciences* **358** (1435): 1197–1204, doi:10.1098/rstb.2003.1317, PMC 1693218, PMID 12903653.
- Howe, J. (November 1994), *Artificial Intelligence at Edinburgh University : a Perspective* (http://www.dai.ed.ac.uk/AI_at_Edinburgh_perspective.html), retrieved 30 August 2007
- Johnson, Mark (1987), *The body in the mind*, Chicago, ISBN 0-226-40317-3
- Kurzweil, Ray (2005), *The Singularity is Near*, Viking Press
- Lighthill, Professor Sir James (1973), "Artificial Intelligence: A General Survey", *Artificial Intelligence: a paper symposium*, Science Research Council
- Luger, George; Stubblefield, William (2004), *Artificial Intelligence: Structures and Strategies for Complex Problem Solving* (http://www.cs.unm.edu/~luger/ai-final/tocfull.html) (5th ed.), The Benjamin/Cummings Publishing Company, Inc., p. 720, ISBN 0-8053-4780-1
- McCarthy, John (Oct 2007), "From here to human-level AI", *Artificial Intelligence* **171** (18): 1174–1182, doi:10.1016/j.artint.2007.10.009.
- McCorduck, Pamela (2004), *Machines Who Think* (http://www.pamelamc.com/html/machines_who_think.html) (2nd ed.), Natick, MA: A. K. Peters, Ltd., ISBN 1-56881-205-1
- Moravec, Hans (1976), *The Role of Raw Power in Intelligence* (http://www.frc.ri.cmu.edu/users/hpm/project.archive/general.articles/1975/Raw.Power.html)
- Moravec, Hans (1988), *Mind Children*, Harvard University Press
- Nagel (1974), "What Is it Like to Be a Bat" (http://organizations.utep.edu/Portals/1475/nagel_bat.pdf), *Philosophical Review*: 435–50..
- Newell, Allen; Simon, H. A. (1963), "GPS: A Program that Simulates Human Thought", in Feigenbaum, E.A.; Feldman, J., *Computers and Thought*, New York: McGraw-Hill
- Newell, Allen; Simon, H. A. (1976), *Computer Science as Empirical Inquiry: Symbols and Search* (http://portal.acm.org/citation.cfm?id=360022), "Communications of the ACM", *Communications of the ACM* **19** (3): 113–126, doi:10.1145/360018.360022
- Nilsson, Nils (1998), *Artificial Intelligence: A New Synthesis*, Morgan Kaufmann Publishers, ISBN 978-1-55860-467-4
- Russell, Stuart J.; Norvig, Peter (2003), *Artificial Intelligence: A Modern Approach* (http://aima.cs.berkeley.edu/) (2nd ed.), Upper Saddle River, New Jersey: Prentice Hall, ISBN 0-13-790395-2
- NRC (1999), "Developments in Artificial Intelligence" (http://www.nap.edu/readingroom/books/far/ch9.html), *Funding a Revolution: Government Support for Computing Research*, National Academy Press, retrieved 30 August 2007
- Poole, David; Mackworth, Alan; Goebel, Randy (1998), *Computational Intelligence: A Logical Approach* (http://www.cs.ubc.ca/spider/poole/ci.html), New York: Oxford University Press
- Searle, John (1980), "Minds, Brains and Programs" (http://www.bbsonline.org/documents/a/00/00/04/84/bbs00000484-00/bbs.searle2.html), *Behavioral and Brain Sciences* **3** (3): 417–457, doi:10.1017/S0140525X00005756
- Simon, H. A. (1965), *The Shape of Automation for Men and Management*, New York: Harper & Row
- Sutherland, J.G. (1990), "Holographic Model of Memory, Learning, and Expression", *International Journal of Neural Systems* **1-3**: 256–267.
- Williams RW, Herrup K (1988), "The control of neuron number", *Annual Review of Neuroscience* **11**: 423–53, doi:10.1146/annurev.ne.11.030188.002231, PMID 3284447.
- de Vega, Manuel; Glenberg, Arthur; Graesser, Arthur, eds. (2008), *Symbols and Embodiment: Debates on meaning and cognition*, Oxford University Press, ISBN 0-19-921727-0
- Voss, Peter (2006), Goertzel, Ben; Pennachin, Cassio, eds., Essentials of general intelligence *Artificial General Intelligence* (http://www.adaptiveai.com/research/index.htm#different_approach), Springer,

doi:10.1146/annurev.psych.49.1.585;jsessionid=o4K4TVe3OdBd, ISBN 3-540-23733-X
- Wang, Pei (2006), website *Artificial General Intelligence : A Gentle Introduction* (http://sites.google.com/site/narswang/home/agi-introduction)
- Yudkowsky, Eliezer (2006), Goertzel, Ben; Pennachin, Cassio, eds., *Artificial General Intelligence* (http://www.singinst.org/upload/LOGI//LOGI.pdf), Springer, doi:10.1146/annurev.psych.49.1.585;jsessionid=o4K4TVe3OdBd, ISBN 3-540-23733-X
- Zucker, Jean-Daniel (July 2003), "A grounded theory of abstraction in artificial intelligence", *Philosophical Transactions: Biological Sciences* **358** (1435): 1293–1309, doi:10.1098/rstb.2003.1308, PMC 1693211, PMID 12903672.
- Yudkowsky, Eliezer (2008), "Artificial Intelligence as a Positive and Negative Factor in Global Risk", *Global Catastrophic Risks* (Oxford University Press).

External links

- The AGI portal maintained by Pei Wang (http://sites.google.com/site/narswang/home/agi-introduction)
- GPAI Project (http://wiki.gpai.cc/index.php/GPAI_Project) A Mass Collaboration for Strong AI
- AND Corporation (http://www.andcorporation.com) - a neuromorphic model based on holographic neural processing
- Expanding Frontiers of Humanoid Robots (http://www.inl.gov/adaptiverobotics/humanoidrobotics/pubs/special-issue.pdf)
- GAIuS (http://gaius-framework.sourceforge.net) - General Artificial Intelligence using Software open-source project.
- AI lectures from Tokyo hosted by Rolf Pfeifer (http://tokyolectures.org/lectures)
- Artificial General Intelligence Research Institute (http://agiri.org/)
- The Genesis Group at MIT's CSAIL (http://genesis.csail.mit.edu/index.html) — Modern research on the computations that underlay human intelligence
- Essentials of general intelligence (http://www.adaptiveai.com/research/index.htm#different_approach), article at Adaptive AI.
- OpenCog - open source project to develop a human-level AI (http://www.opencog.org/)
- Wiki of the Artificial General Intelligence Research Institute (http://agiri.org/)
- Problems with Thinking Robots (http://www.inl.gov/adaptiverobotics/humanoidrobotics/pastproblems.shtml)
- www.eng.warwick.ac.uk (http://www.eng.warwick.ac.uk/postgrad/msc-mods/msc-synthgen.htm)
- Simulating logical human thought (http://academia.wikia.com/wiki/A_Method_for_Simulating_the_Process_of_Logical_Human_Thought)
- Texai (http://texai.org), An open source project to create artificial intelligence
- The Game of Intelligent Design (http://gameofid.com), An online game that promotes the development of artificial general intelligence
- The Practical Strong AI Project (http://www.practicalai.org/Strategy.aspx), A Practical approach and strategy for strong AI.
- Artificial Intelligence as a Positive and Negative Factor in Global Risk (http://singinst.org/upload/artificial-intelligence-risk.pdf)

Progress in artificial intelligence

Artificial intelligence has been used in a wide range of fields including medical diagnosis, stock trading, robot control, law, scientific discovery and toys. However, many AI applications are not perceived as AI: "A lot of cutting edge AI has filtered into general applications, often without being called AI because once something becomes useful enough and common enough it's not labeled AI anymore."[1] "Many thousands of AI applications are deeply embedded in the infrastructure of every industry."[2] In the late 90s and early 21st century, AI technology became widely used as elements of larger systems,[2][3] but the field is rarely credited for these successes.

To allow comparison with human performance, artificial intelligence can be evaluated on constrained and well-defined problems. Such tests have been termed subject matter expert Turing tests. Also, smaller problems provide more achievable goals and there are an ever-increasing number of positive results.

Performance evaluation

The broad classes of outcome for an AI test are:

- **optimal**: it is not possible to perform better
- **strong super-human**: performs better than all humans
- **super-human**: performs better than most humans
- **par-human**: performs similarly to most humans
- **sub-human**: performs worse than most humans

Optimal

- Tic-Tac-Toe
- Connect Four
- Checkers[4]
- Rubik's Cube[5]

See also solved games.

Super-human

- Backgammon: super-human[6]
- Bridge: nearing strong super-human[7]
- Chess: nearing strong super-human[8]
- Crosswords: super-human[9]
- Jigsaw puzzles: strong super-human[10]
- Reversi: strong super-human[11]
- Scrabble: strong super-human[12]
- Quiz show question answering: strong super-human[13][14]

Par-human

- Optical character recognition for ISO 1073-1:1976 and similar special characters.
- Go

Sub-human

- Optical character recognition for printed text (nearing par-human for Latin-script typewritten text)
- Handwriting recognition
- Autonomous driverless cars[15]
- Object recognition
- Translation[16]
- Speech recognition
- Word-sense disambiguation
- Computer poker players, sub-human for full ring Texas hold 'em (approaching strong super-human in simpler versions of poker)[17][18][19]
- Most everyday tasks performed by humans.

External links

- http://www.human-competitive.org/

References

[1] AI set to exceed human brain power (http://www.cnn.com/2006/TECH/science/07/24/ai.bostrom/) CNN.com (July 26, 2006)
[2] Kurtzweil 2005, p. 264
[3] NRC 1999 under "Artificial Intelligence in the 90s"
[4] doi: 10.1126/science.1144079
This citation will be automatically completed in the next few minutes. You can jump the queue or expand by hand (http://en.wikipedia.org/wiki/Template:cite_doi/_10.1126.2fscience.1144079?preload=Template:Cite_doi/preload&editintro=Template:Cite_doi/editintro&action=edit)
[5] "God's Number is 20" (http://www.cube20.org/)
[6] Tesauro, Gerald (March 1995). "Temporal difference learning and TD-Gammon" (http://www.research.ibm.com/massive/tdl.html). *Communications of the ACM* **38** (3): 58–68. doi:10.1145/203330.203343. .
[7] Computer bridge#Computers versus humans
[8] Computer Chess#Computers versus humans
[9] Proverb: The probabilistic cruciverbalist. By Greg A. Keim, Noam Shazeer, Michael L. Littman, Sushant Agarwal, Catherine M. Cheves, Joseph Fitzgerald, Jason Grosland, Fan Jiang, Shannon Pollard, and Karl Weinmeister. 1999. In Proceedings of the Sixteenth National Conference on Artificial Intelligence, 710-717. Menlo Park, Calif.: AAAI Press.
[10] http://www.physorg.com/news193908598.html
[11] Reversi#Computer_opponents
[12] Sheppard, B. (2002). "World-championship-caliber Scrabble". *Artificial Intelligence* **134**: 241–275. doi:10.1016/S0004-3702(01)00166-7.
[13] Watson beats Jeopardy grand-champions. http://www.nytimes.com/2011/02/17/science/17jeopardy-watson.html
[14] Jackson, Joab. "IBM Watson Vanquishes Human Jeopardy Foes" (http://www.pcworld.com/businesscenter/article/219893/ibm_watson_vanquishes_human_jeopardy_foes.html). IDG News. PC World. . Retrieved 2011-02-17.
[15] Markoff, John (October 9, 2010). "Google Cars Drive Themselves, in Traffic" (http://www.nytimes.com/2010/10/10/science/10google.html?_r=1&src=tptw). *The New York Times*. .
[16] There are several ways of evaluating machine translation systems. People competent in a second language frequently outperform machine translation systems but the average person is often less capable. Some machine translation systems are capable of a large number of languages, like google translate, and as a result have a broader competence than most humans. For example, very few humans can translate from Arabic to Polish *and* French to Swahili *and* Armenian to Vietnamese. When comparing over several languages machine translation systems will tend to outperform humans.
[17] Rubin, Jonathan; Watson, Ian (2011). "Computer poker: A review". *Artificial Intelligence*. doi:10.1016/j.artint.2010.12.005.
[18] "Polaris drawing professionals to a stand-still" (http://www.expressnews.ualberta.ca/article.cfm?id=8611). University of Alberta: Express News. July 20, 2007. .

[19] Ryan Smith (August 9, 2006). "U of A researchers win computer poker title" (http://www.expressnews.ualberta.ca/article.cfm?doi=7789). University of Alberta: Express News. .

List of artificial intelligence projects

The following is a list of current and past notable artificial intelligence projects.

Specialized projects

Brain simulation

- aHuman [1], hybrid of latest neurobiology data and Numenta findings aimed to implement human personality by means of computer program, started in 2008 as independent research.
- Blue Brain Project, an attempt to create a synthetic brain by reverse-engineering the mammalian brain down to the molecular level.
- HNeT (Holographic Neural Technology), a technology by AND Corporation (Artificial Neural Devices) [2] based on non linear phase coherence/decoherence principles.
- Hierarchical Temporal Memory, a technology by Numenta to capture and replicate the properties of the neocortex.
- Visual Hierarchical Modular Neural Network, a software technology by TinMan Systems [3] to visually construct a flow of human thought and logic to produce autonomous artificial intelligence.

Cognitive architectures

- 4CAPS, developed at Carnegie Mellon University under Marcel A. Just
- ACT-R, developed at Carnegie Mellon University under John R. Anderson.
- PreAct, developed under Dr. Norm Geddes at ASI.
- Apex developed under Michael Freed at NASA Ames Research Center.
- CALO, a DARPA-funded, 25-institution effort to integrate many artificial intelligence approaches (natural language processing, speech recognition, machine vision, probabilistic logic, planning, reasoning, many forms of machine learning) into an AI assistant that learns to help manage your office environment.
- CHREST, developed under Fernand Gobet at Brunel University and Peter C. Lane at the University of Hertfordshire.
- CLARION the cognitive architecture, developed under Ron Sun at Rensselaer Polytechnic Institute and University of Missouri.
- CoJACK, an ACT-R inspired extension to the JACK multi-agent system that adds a cognitive architecture to the agents for eliciting more realistic (human-like) behaviors in virtual environments.
- Copycat, by Douglas Hofstadter and Melanie Mitchell at the Indiana University.
- DUAL, developed at the New Bulgarian University under Boicho Kokinov.
- EPIC, developed under David E. Kieras and David E. Meyer at the University of Michigan.
- The H-Cogaff architecture, which is a special case of the CogAff schema; see Taylor & Sayda, and Sloman refs below.
- FORR developed by Susan L. Epstein at The City University of New York.
- IDA and LIDA, implementing Global Workspace Theory, developed under Stan Franklin at the University of Memphis.
- OpenCog Prime, developed using the OpenCog Framework.
- PRODIGY, by Veloso et al.
- Procedural Reasoning System (PRS), developed by Michael Georgeff and Amy L. Lansky at SRI International.

- Psi-Theory developed under Dietrich Dörner at the Otto-Friedrich University in Bamberg, Germany.
- R-CAST, developed at the Pennsylvania State University.
- Soar, developed under Allen Newell and John Laird at Carnegie Mellon University and the University of Michigan.
- Society of mind and its successor the Emotion machine proposed by Marvin Minsky.
- Subsumption architectures, developed e.g. by Rodney Brooks (though it could be argued whether they are *cognitive*).

Games

- Chinook, a computer program that plays English draughts; the first to win the world champion title in the competition against humans.
- Deep Blue, a chess-playing computer developed by IBM which beat Garry Kasparov in 1997.
- FreeHAL, a self-learning conversation simulator (chatterbot) which uses semantic nets to organize its knowledge to imitate a very close human behavior within conversations.
- Poki, research into computer poker by the University of Alberta.
- TD-Gammon, a program that learned to play world-class backgammon partly by playing against itself (temporal difference learning with neural networks).

Knowledge and reasoning

- Cyc, an attempt to assemble an ontology and database of everyday knowledge, enabling human-like reasoning.
- Eurisko, a language by Douglas Lenat for solving problems which consists of heuristics, including some for how to use and change its heuristics.
- Mycin, an early medical expert system.
- Open Mind Common Sense, a project based at the MIT Media Lab to build a large common sense knowledge base from online contributions.
- P.A.N., a publicly available text analyzer.
- Questsin, uses Query by Example and features a dictionary, knowledge base, repository, reference, and thesaurus.
- Siri, a voice-interface artificial intelligence program built into the iPhone 4S.
- SNePS, a simultaneously a logic-based, frame-based, and network-based knowledge representation, reasoning, and acting system.
- Watson, a question answering system developed by IBM to play the Jeopardy! gameshow.
- Wolfram Alpha, an online service that answers factual queries directly by computing the answer from structured data, capable of responding to particularly phrased natural-language fact-based questions.

Motion and manipulation

- Cog, a robot developed by MIT to study theories of cognitive science and artificial intelligence, now discontinued.
- Grand Challenge 5 – Architecture of Brain and Mind, a UK attempt to understand and model natural intelligence at various levels of abstraction, demonstrating results in a succession of increasingly sophisticated working robots.

Natural language processing

- AIML, an XML dialect for creating natural language software agents.
- Artificial Linguistic Internet Computer Entity (A.L.I.C.E.), an award-winning natural language processing chatterbot.
- Dushka [4], a Russian artificial intelligence that thinks in Russian.
- ELIZA, a famous 1966 computer program by Joseph Weizenbaum, which parodied person-centered therapy.
- InfoTame, a text analysis search engine originally developed by the KGB for sorting communications intercepts.
- Jabberwacky, a chatterbot by Rollo Carpenter, aiming to simulate a natural human chat.
- KAR-Talk, a chatterbot by I.-A.Industrie.
- KAR Intelligent Computer, an artificial intelligence software included in the CEPC 230 KAR's computer from Continental Edison.
- PARRY, another early famous chatterbot, written in 1972 by Kenneth Colby, attempting to simulate a paranoid schizophrenic.
- Proverb, a system that can solve crossword puzzles better than most humans.[5]
- SHRDLU, an early natural language processing computer program developed by Terry Winograd at MIT from 1968 to 1970.
- START, the world's first web-based question answering system, developed at the MIT CSAIL.
- SYSTRAN, a machine translation technology by a company of the same name, used by Yahoo!, AltaVista and Google, among others.
- Texai, an open source project to create artificial intelligence, starting with a bootstrap English dialog system that intelligently acquires knowledge and behaviors.

Planning

- O-Plan, a project to provide a modular and flexible planning and control system using AI, at Artificial Intelligence Applications Institute (AIAI), University of Edinburgh.

Other

- Kreator, an optimization problem solving software by Intelligentics that uses A.I. techniques.
- OpenAIR, a routing and communication protocol based on a publish-subscribe architecture, built especially for A.I. research.
- Synthetic Environment for Analysis and Simulations (SEAS), a model of the real world used by Homeland security and the United States Department of Defense that uses simulation and AI to predict and evaluate future events and courses of action.[6]

Multipurpose projects

Software libraries

- dANN,[7] a freely available AI library implemented in Java, implementing graph theory, ANN, GA, Markov Chains, graphical models (bayesian networks, HMM), etc.
- ELKI,[8] a research project and software framework with many data mining algorithms (in particular cluster analysis and outlier detection) and index structures by the Ludwig Maximilian University of Munich.
- FRDCSA,[9] an attempt to package and integrate all FOSS AI systems for GNU+Linux-based systems.
- I-X, a systems integration architecture project for the creation of intelligent systems at Artificial Intelligence Applications Institute (AIAI), University of Edinburgh.
- OpenCog, a GPL-licensed framework for machine learning, genetic programming, probabilistic reasoning, natural language processing and virtual world embodiment, written in C++, Python and Scheme.
- RapidMiner, an environment for machine learning and data mining, developed by the Dortmund University of Technology.
- Weka, a free implementation of many machine learning algorithms in Java.
- Pogamut,[10] a free platform for Java AI development in games, developed by the Charles University in Prague
- CILib,[11] a library of different computational intelligence algorithms and supporting APIs, supporting different paradigms: Swarm Intelligence, Evolutionary Computation, Neural Networks, Game Playing (developed by the Computational Intelligence Research Group (CIRG@UP) Department of Computer Science University of Pretoria South Africa).

Cloud services

- Data Applied, a web based data mining environment.

External links

- SourceForge AI projects [12]

References

[1] http://code.google.com/p/ahuman/
[2] http://www.andcorporation.com/
[3] http://www.tinmansystems.com
[4] http://www.scn.org/~mentifex/Dushka.html
[5] Proverb: The probabilistic cruciverbalist (AAAI–99 Outstanding Paper Award). By Greg A. Keim, Noam Shazeer, Michael L. Littman, Sushant Agarwal, Catherine M. Cheves, Joseph Fitzgerald, Jason Grosland, Fan Jiang, Shannon Pollard, and Karl Weinmeister. 1999. In Proceedings of the Sixteenth National Conference on Artificial Intelligence, 710-717. Menlo Park, Calif.: AAAI Press.
[6] The Register (http://www.theregister.co.uk/2007/06/23/sentient_worlds/) article *Sentient world: war games on the grandest scale* published 23 June 2007
[7] dANN Homepage (http://wiki.syncleus.com/index.php/DANN)
[8] ELKI Homepage (http://www.dbs.ifi.lmu.de/research/KDD/ELKI/)
[9] FRDCSA Homepage (http://www.frdcsa.org/)
[10] Pogamut Homepage (http://pogamut.cuni.cz)
[11] CILib (http://cilib.net/)
[12] http://sourceforge.net/search/?&fq%5B%5D=trove%3A97&fq%5B%5D=trove%3A133

Applications of artificial intelligence

Artificial intelligence has been used in a wide range of fields including medical diagnosis, stock trading, robot control, law, scientific discovery and toys. However, many AI applications are not perceived as AI: "A lot of cutting edge AI has filtered into general applications, often without being called AI because once something becomes useful enough and common enough it's not labeled AI anymore," Nick Bostrom reports.[1] "Many thousands of AI applications are deeply embedded in the infrastructure of every industry."[2] the late 90s and early 21st century, AI technology became widely used as elements of larger systems,[2][3] but the field is rarely credited for these successes.

Computer science

AI researchers have created many tools to solve the most difficult problems in computer science. Many of their inventions have been adopted by mainstream computer science and are no longer considered a part of AI. (See AI effect). According to Russell & Norvig (2003, p. 15), all of the following were originally developed in AI laboratories: time sharing, interactive interpreters, graphical user interfaces and the computer mouse, rapid development environments, the linked list data structure, automatic storage management, symbolic programming, functional programming, dynamic programming and object-oriented programming.

Finance

Banks use artificial intelligence systems to organize operations, invest in stocks, and manage properties. In August 2001, robots beat humans in a simulated financial trading competition.[4]

Financial institutions have long used artificial neural network systems to detect charges or claims outside of the norm, flagging these for human investigation.

Creative Virtual [5] has deployed artificial intelligence customer support systems, or automated online assistants, at E*TRADE, HSBC, Intuit and Lloyds Banking Group, to assist financial services customers with services such as checking an account balance, signing up for a new credit card or retrieving a forgotten password.

Hospitals and medicine

A medical clinic can use artificial intelligence systems to organize bed schedules, make a staff rotation, and provide medical information.

Artificial neural networks are used as clinical decision support systems for medical diagnosis, such as in Concept Processing technology in EMR software.

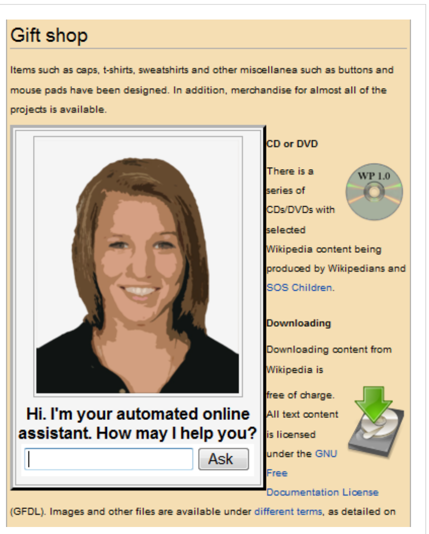
Other tasks in medicine that can potentially be performed by artificial intelligence include:

- Computer-aided interpretation of medical images. Such systems help scan digital images, *e.g.* from computed tomography, for typical appearances and to highlight conspicuous sections, such as possible diseases. A typical application is the detection of a tumor.
- Heart sound analysis[6]

Heavy industry

Robots have become common in many industries. They are often given jobs that are considered dangerous to humans. Robots have proven effective in jobs that are very repetitive which may lead to mistakes or accidents due to a lapse in concentration and other jobs which humans may find degrading. Japan is the leader in using and producing robots in the world. In 1999, 1,700,000 robots were in use worldwide. For more information, see survey[7] about artificial intelligence in business.

Online and telephone customer service



An automated online assistant providing customer service on a web page.

Artificial intelligence is implemented in automated online assistants that can be seen as avatars on web pages.[8] It can avail for enterprises to reduce their operation and training cost.[8] A major underlying technology to such systems is natural language processing.[8]

Similar techniques may be used in answering machines of call centres, such as speech recognition software to allow computers to handle first level of customer support, text mining and natural language processing to allow better customer handling, agent training by automatic mining of best practices from past interactions, support automation and many other technologies to improve agent productivity and customer satisfaction.[9]

Transportation

Fuzzy logic controllers have been developed for automatic gearboxes in automobiles (the 2006 Audi TT, VW Toureg and VW Caravell feature the DSP transmission which utilizes Fuzzy Logic, a number of Škoda variants (Škoda Fabia) also currently include a Fuzzy Logic based controller).

Telecommunications

Many telecommunications companies make use of heuristic search in the management of their workforces, for example BT Group has deployed heuristic search[10] in a scheduling application that provides the work schedules of 20,000 engineers.

Toys and games

The 1990s saw some of the first attempts to mass-produce domestically aimed types of basic Artificial Intelligence for education, or leisure. This prospered greatly with the Digital Revolution, and helped introduce people, especially children, to a life of dealing with various types of Artificial Intelligence, specifically in the form of Tamagotchis and Giga Pets, the Internet (example: basic search engine interfaces are one simple form), and the first widely released robot, Furby. A mere year later an improved type of domestic robot was released in the form of Aibo, a robotic dog with intelligent features and autonomy. AI has also been applied to video games.

Music

The evolution of music has always been affected by technology. With AI, scientists are trying to make the computer emulate the activities of the skillful musician. Composition, performance, music theory, sound processing are some of the major areas on which research in Music and Artificial Intelligence are focusing.

Aviation

The Air Operations Division AOD, uses AI for the rule based expert systems. The AOD has use for artificial intelligence for surrogate operators for combat and training simulators, mission management aids, support systems for tactical decision making, and post processing of the simulator data into symbolic summaries.

The use of artificial intelligence in simulators is proving to be very useful for the AOD. Airplane simulators are using artificial intelligence in order to process the data taken from simulated flights. Other than simulated flying, there is also simulated aircraft warfare. The computers are able to come up with the best success scenarios in these

situations. The computers can also create strategies based on the placement, size, speed, and strength of the forces and counter forces. Pilots may be given assistance in the air during combat by computers. The artificial intelligent programs can sort the information and provide the pilot with the best possible maneuvers, not to mention getting rid of certain maneuvers that would be impossible for a human being to perform. Multiple aircraft are needed to get good approximations for some calculations so computer simulated pilots are used to gather data. These computer simulated pilots are also used to train future air traffic controllers.

The system used by the AOD in order to measure performance was the Interactive Fault Diagnosis and Isolation System, or IFDIS. It is a rule based expert system put together by collecting information from TF-30 documents and the expert advice from mechanics that work on the TF-30. This system was designed to be used to for the development of the TF-30 for the RAAF F-111C. The performance system was also used to replace specialized workers. The system allowed the regular workers to communicate with the system and avoid mistakes, miscalculations, or having to speak to one of the specialized workers.

The AOD also uses artificial intelligence in speech recognition software. The air traffic controllers are giving directions to the artificial pilots and the AOD wants to the pilots to respond to the ATC’s with simple responses. The programs that incorporate the speech software must be trained, which means they use neural networks. The program used, the Verbex 7000, is still a very early program that has plenty of room for improvement. The improvements are imperative because ATCs use very specific dialog and the software needs to be able to communicate correctly and promptly every time.

The Artificial Intelligence supported Design of Aircraft [11], or AIDA, is used to help designers in the process of creating conceptual designs of aircraft. This program allows the designers to focus more on the design itself and less on the design process. The software also allows the user to focus less on the software tools. The AIDA uses rule based systems to compute its data. This is a diagram of the arrangement of the AIDA modules. Although simple, the program is proving effective.

In 2003, NASA’s Dryden Flight Research Center, and many other companies, created software that could enable a damaged aircraft to continue flight until a safe landing zone can be reached. The software compensates for all the damaged components by relying on the undamaged components. The neural network used in the software proved to be effective and marked a triumph for artificial intelligence.

The Integrated Vehicle Health Management system, also used by NASA, on board an aircraft must process and interpret data taken from the various sensors on the aircraft. The system needs to be able to determine the structural integrity of the aircraft. The system also needs to implement protocols in case of any damage taken the vehicle.

News and publishing

The company Narrative Science makes computer generated news and reports commercially available, including summarizing team sporting events based on statistical data from the game. It also creates financial reports and real estate analyses.[12]

Other

Various tools of artificial intelligence are also being widely deployed in homeland security, speech and text recognition, data mining, and e-mail spam filtering. Applications are also being developed for gesture recognition (understanding of sign language by machines), individual voice recognition, global voice recognition (from a variety of people in a noisy room), facial expression recognition for interpretation of emotion and non verbal queues. Other applications are robot navigation, obstacle avoidance, and object recognition.

List of applications

Typical problems to which AI methods are applied

- Pattern recognition
  - Optical character recognition
  - Handwriting recognition
  - Speech recognition
  - Face recognition
- Artificial Creativity
- Computer vision, Virtual reality and Image processing
- Diagnosis (artificial intelligence)
- Game theory and Strategic planning
- Game artificial intelligence and Computer game bot
- Natural language processing, Translation and Chatterbots
- Nonlinear control and Robotics

Other fields in which AI methods are implemented

- Artificial life
- Automated reasoning
- Automation
- Biologically inspired computing
- Concept mining
- Data mining
- Knowledge representation
- Semantic Web
- E-mail spam filtering
- Robotics
  - Behavior-based robotics
  - Cognitive
  - Cybernetics
  - Developmental robotics
  - Epigenetic robotics
  - Evolutionary robotics
- Hybrid intelligent system
- Intelligent agent
- Intelligent control
- Litigation

External links

- AI applications at www.aaai.org [13]

Notes

[1] AI set to exceed human brain power (http://www.cnn.com/2006/TECH/science/07/24/ai.bostrom/) CNN.com (July 26, 2006)
[2] Kurzweil 2005, p. 264
[3] NRC 1999, "Artificial Intelligence in the 90s"
[4] Robots Beat Humans in Trading Battle. (http://news.bbc.co.uk/2/hi/business/1481339.stm) BBC.com (August 8th, 2001)
[5] http://www.creativevirtual.com/
[6] Reed, T. R.; Reed, N. E.; Fritzson, P. (2004). "Heart sound analysis for symptom detection and computer-aided diagnosis". *Simulation Modelling Practice and Theory* **12** (2): 129. doi:10.1016/j.simpat.2003.11.005.
[7] Nordlander, Tomas Eric (2001). "AI Surveying: Artificial Intelligence In Business" (http://www.4c.ucc.ie/web/upload/publications/mastersThesis/Artificial_Intelligence_in_Business.pdf) (PDF). (MS Thesis), De Montfort University. . Retrieved 2007-11-04.
[8] Implementing an online help desk system based on conversational agent (http://portal.acm.org/citation.cfm?id=1643823.1643908) Authors: Alisa Kongthon, Chatchawal Sangkeettrakarn, Sarawoot Kongyoung and Choochart Haruechaiyasak. Published by ACM 2009 Article, Bibliometrics Data Bibliometrics. Published in: Proceeding, MEDES '09 Proceedings of the International Conference on Management of Emergent Digital EcoSystems, ACM New York, NY, USA. ISBN 978-1-60558-829-2, doi:10.1145/1643823.1643908
[9] L Venkata Subramaniam (2008-02-01). "Call Centers of the Future" (http://lvs004.googlepages.com/callcenters.pdf) (PDF). i.t. magazine. pp. 48–51. . Retrieved 2008-05-29.
[10] Success Stories (http://www.theorsociety.com/Science_of_Better/htdocs/prospect/can_do/success_stories/dwsbt.htm).
[11] http://www.kbs.twi.tudelft.nl/Research/Projects/AIDA/

[12] http://www.narrativescience.com/solutions.html
[13] http://www.aaai.org/AITopics/html/applications.html

References

- Russell, Stuart J.; Norvig, Peter (2003). *Artificial Intelligence: A Modern Approach* (http://aima.cs.berkeley.edu/) (2nd ed.). Upper Saddle River, New Jersey: Prentice Hall. ISBN 0-13-790395-2
- Kurzweil, Ray (2005). *The Singularity is Near: When Humans Transcend Biology*. New York: Viking. ISBN 978-0-670-03384-3
- National Research Council (1999). "Developments in Artificial Intelligence". *Funding a Revolution: Government Support for Computing Research*. National Academy Press. ISBN 0-309-06278-0. OCLC 246584055.

Augmented reality

Augmented reality (AR) is a live, direct or indirect, view of a physical, real-world environment whose elements are *augmented* by computer-generated sensory input such as sound, video, graphics or GPS data. It is related to a more general concept called mediated reality, in which a view of reality is modified (possibly even diminished rather than augmented) by a computer. As a result, the technology functions by enhancing one's current perception of reality.[1] By contrast, virtual reality replaces the real world with a simulated one.[2][3] Augmentation is conventionally in real-time and in semantic context with environmental elements, such as sports scores on TV during a match. With the help of advanced AR technology (e.g. adding computer vision and object recognition) the information about the surrounding real world of the user becomes interactive and digitally manipulable. Artificial information about the environment and its objects can be overlaid on the real world.[4][5][6][7]

Wikitude World Browser on the iPhone 3GS uses GPS and a solid state compass

Samsung SARI AR SDK markerless tracker used in the *AR EdiBear* game (Android OS)

Research explores the application of computer-generated imagery in live-video streams as a way to enhance the perception of the real world. AR technology includes head-mounted displays and virtual retinal displays for visualization purposes, and construction of controlled environments containing sensors and actuators.

Technology

Hardware

The main hardware components for augmented reality are: processor, display, sensors and input devices. These elements, specifically CPU, display, camera and MEMS sensors such as accelerometer, GPS, solid state compass are often present in modern smartphones, which make them prospective AR platforms.

Display

Various technologies are used in Augmented Reality rendering including optical projection systems, monitors, hand held devices, and display systems worn on one's person such as head mounted displays.

AR Tower Defense game on the Nokia N95 smartphone (Symbian OS) uses fiduciary markers

Head-mounted

A head-mounted display (HMD) places images of both the physical world and registered virtual graphical objects over the user's view of the world. The HMDs are either *optical see-through* or *video see-through*.[8][9] Optical see-through employs half-silver mirrors to pass images through the lens and overlay information to be reflected into the user's eyes.[10][11] The HMD can be tracked with sensor that provides six degrees of freedom. This tracking allows the system to align virtual information to the physical world.[12][13] The main advantage of HMD AR is the user's immersive experience. The graphical information is slaved to the view of the user. The most common products employed are as follows: MicroVision Nomad,[14] Sony Glasstron,[15] Vuzix,[16] Lumus[17] and LASTER Technologies.[18][19]

Augmented reality map on iPhone

While the *The New York Times* reported Google wished to start selling virtual eyeglasses not only for entertainment but also for information and augmented reality by the end of 2012,[20] more recent statements from Google about "Project Glass" have said a 2012 commercial release is unlikely.[21]

Handheld

Handheld displays employ a small display that fits in a user's hand. All handheld AR solutions to date opt for video see-through. Initially handheld AR employed fiduciary markers,[22] and later GPS units and MEMS sensors such as digital compasses and six degrees of freedom accelerometer–gyroscope. Today SLAM markerless trackers such as PTAM are starting to come into use. Handheld display AR promises to be the first commercial success for AR technologies. The two main advantages of handheld AR is the portable nature of handheld devices and ubiquitous nature of camera phones. The disadvantages are the physical constraints of the user having to hold the handheld device out in front of them at all times as well as distorting effect of classically wide-angled mobile phone cameras when compared to the real world as viewed through the eye.[23]

Spatial

Spatial Augmented Reality (SAR) augments real world objects and scenes without the use of special displays such as monitors, head mounted displays or hand-held devices. SAR makes use of digital projectors to display graphical information onto physical objects. The key difference in SAR is that the display is separated from the users of the system. Because the displays are not associated with each user, SAR scales naturally up to groups of users, thus allowing for collocated collaboration between users. SAR has several advantages over traditional head-mounted displays and handheld devices. The user is not required to carry equipment or wear the display over their eyes. This makes spatial AR a good candidate for collaborative work, as the users can see each other’s faces. A system can be used by multiple people at the same time without each having to wear a head-mounted display.

Examples include shader lamps, mobile projectors, virtual tables, and smart projectors. Shader lamps mimic and augment reality by projecting imagery onto neutral objects, providing the opportunity to enhance the object’s appearance with materials of a simple unit- a projector, camera, and sensor. Handheld projectors further this goal by enabling cluster configurations of environment sensing, reducing the need for additional peripheral sensing.[24][25]

Other tangible applications include table and wall projections. One such innovation, the Extended Virtual Table, separates the virtual from the real by including beam-splitter mirrors attached to the ceiling at an adjustable angle.[26] Virtual showcases, which employ beam-splitter mirrors together with multiple graphics displays, provide an interactive means of simultaneously engaging with the virtual and the real.[27][28] Altogether, current augmented reality display technology can be applied to improve design and visualization, or function as scientific simulations and tools for education or entertainment. Many more implementations and configurations make spatial augmented reality display an increasingly attractive interactive alternative.[19]

Spatial AR does not suffer from the limited display resolution of current head-mounted displays and portable devices. A projector based display system can simply incorporate more projectors to expand the display area. Where portable devices have a small window into the world for drawing, a SAR system can display on any number of surfaces of an indoor setting at once. The drawbacks, however, are that SAR systems of projectors do not work so well in sunlight and also require a surface on which to project the computer-generated graphics. Augmentations cannot simply hang in the air as they do with handheld and HMD-based AR. The tangible nature of SAR, though, makes this an ideal technology to support design, as SAR supports both a graphical visualisation and passive haptic sensation for the end users. People are able to touch physical objects, and it is this process that provides the passive haptic sensation.[7][29][30][31][32]

Tracking

Modern mobile augmented reality systems use one or more of the following tracking technologies: digital cameras and/or other optical sensors, accelerometers, GPS, gyroscopes, solid state compasses, RFID and wireless sensors. These technologies offer varying levels of accuracy and precision. Most important is the position and orientation of the user's head. Tracking the user's hand(s) or a handheld input device can provide a 6DOF interaction technique.[33]

Input devices

Techniques include the pinch glove,[34] mouse gloves, [35]wands[36][37] and body gesture recognition sensors.[38][39][40]

Computer

The computer analyzes the sensed visual and other data to synthesize and position augmentations.

Software and algorithms

A key measure of AR systems is how realistically they integrate augmentations with the real world. The software must derive real world coordinates, independent from the camera, from camera images. That process is called image registration which uses different methods of computer vision, mostly related to video tracking.[41][42] Many computer vision methods of augmented reality are inherited from visual odometry. Usually those methods consist of two parts.

First detect interest points, or fiduciary markers, or optical flow in the camera images. First stage can use feature detection methods like corner detection, blob detection, edge detection or thresholding and/or other image processing methods. [43][44] The second stage restores a real world coordinate system from the data obtained in the first stage. Some methods assume objects with known geometry (or fiduciary markers) present in the scene. In some of those cases the scene 3D structure should be precalculated beforehand. If part of the scene is unknown simultaneous localization and mapping (SLAM) can map relative positions. If no information about scene geometry is available,

structure from motion methods like bundle adjustment are used. Mathematical methods used in the second stage include projective (epipolar) geometry, geometric algebra, rotation representation with exponential map, kalman and particle filters, nonlinear optimization, robust statistics.

Applications

Augmented reality has many applications, and many areas can benefit from the usage of AR technology. AR was initially used for military, industrial, and medical applications, but was soon applied to commercial and entertainment areas as well.[45]

Archaeology

AR can be used to aid archaeological research, by augmenting archaeological features onto the modern landscape, enabling archaeologists to formulate conclusions about site placement and configuration [46]

Another application given to AR in this field is the possibility for users to rebuild ruins, buildings, or even landscapes as they formerly existed.[47]

Architecture

AR can simulate planned construction projects.[48]

Art

AR can help create art in real time integrating reality such as painting, drawing and modeling. AR art technology has helped disabled individuals to continue pursuing their passion.[49] Recently, Alaskan artist Nathan Shafer created a global warming-oriented AR project, called Exit Glacier AR Terminus. In this project, AR technology (is this case, smartphones) walks the viewer through various positions of South Central Alaska's Exit Glacier, going back three decades. Belgian photographer, Liesje Reyskens recently commissioned Augmented Reality Agency Kudanto produce an AR art installation at the Albus Lux gallery - the AR app recognized her photography and overlaid live animation video to enhance the gallery experience.[50]

Commerce

AR can be used to display certain products at another way. For example, the lego-boxes in the lego-store at Schaumburg use image recognition on a product's packaging to show the product when it's assembled.[51] AR can also be used as an aid in picking clothing through a kiosk.[52] On the web, AR ecommerce software, like the Webcam Social Shopper, is designed to allow retailers to integrate AR into their online retail sites.[53]

Usage of AR to promote products via interactive AR applications is becoming popular now. For example Nissan (2008 LA Auto Show),[54] Best Buy (2009),[55] and others used webcam based AR to connect 3D models with printed materials. There are numerous examples of connecting mobile AR to outdoor advertising[56][57]

On September 2012 the Royal Dutch Mint (Koninklijke Nederlandse Munt) issued the world's first official coin with Augmented Reality. The coin was issued on behalf of the Central Bank of Aruba.The coin itself was able to be scanned with smart phones and displayed a link to a dedicated website.This was the first time AR was used in currency.[58][59]

Education

Augmented reality applications can complement a standard curriculum. Text, graphics, video and audio can be superimposed into a student's real time environment. Textbooks, flashcards and other educational reading material can contain embedded "markers" that, when scanned by an AR device, produce supplementary information to the student rendered in a multimedia format.[60][61][62] Students can participate interactively with computer generated simulations of historical events, exploring and learning details of each significant area of the event site.[63] Augmented reality technology also permits learning via remote collaboration, in which students and instructors not at the same physical location can share a common virtual learning environment populated by virtual objects and learning materials and interact with another within that setting.[64]

Industrial Design

In the area of industrial design AR can provide crucial help, AR can help designer experience the final product before is complete or can help with the testing part of it. Volkswagen is already using AR for comparing calculated and actual crash test imagery.[65] But AR can also be used to visualize and modify a car body curvature or the engine layout of it. AR can also be used to compare digital mock-ups with physical mock-ups for efficiently finding discrepancies between them.[66][67]

Medical

AR can provide the surgeon with information of the heartbeat, the blood pressure, the state of the patient's organ, etc. It can also help the doctor identify the problem with the patient right away. This approach works in a similar as the technicians doing maintenance work. Examples include a virtual X-ray view based on prior tomography or on real time images from ultrasound and confocal microscopy probes[68] or open NMR devices. AR can enhance viewing a fetus inside a mother's womb.[69] See also Mixed reality.

Military

In combat, AR can serve as a networked communication system that renders useful battlefield data onto a soldier's goggles in real time. From the soldier's viewpoint, people and various objects can be marked with special indicators to warn of potential dangers. Virtual maps and 360° view camera imaging can also be rendered to aid a soldier's navigation and battlefield perspective, and this can be transmitted to military leaders at a remote command center.[70]

Navigation

AR can augment the effectiveness of navigation devices. Information can be displayed on the car's windshield indicating information of where the user is going. Not only can information of how to get to the place be offered but so can information about the weather or the terrain. AR can provide traffic information to drivers as well as alert the driver in case of an emergency or highlight objects on the road that might not be caught by the driver's eyes at a first glance. It can also be used in the sea where fishermen can use the technology to display information about the amount of fish that are in the area and how to get to them.[71]

Currently some car manufacturers (e.g. BMW and GM) are using this technology in car windshields to display meter information and traffic information.[72]

Aboard naval and maritime vessels, AR can allow bridge watch-standers to continuously monitor important information such as a ship's heading and speed while moving throughout the bridge or performing other tasks.[73]

Office Workplace

AR can help facilitate collaboration among distributed team members in a work force via conferences with real and virtual participants. AR tasks can include brainstorming and discussion meetings utilizing common visualization via touch screen tables, interactive digital whiteboards, shared design spaces, and distributed control rooms.[74][75][76]

Sports & Entertainment

AR has become common in sports telecasting. Sports and entertainment venues are provided with see-trough and overlay augmentation through tracked camera feeds for enhanced viewing by the audience. Examples include the yellow "first down" line seen in television broadcasts of American football games showing the line the offensive team must cross to receive a first down. AR is also used in association with football and other sporting events to show a commercial advertisements overlayed onto the view of the playing area. Sections of rugby fields and cricket pitches also display sponsored images. Swimming telecasts often add a line across the lanes to indicate the position of the current record holder as a race proceeds to allow viewers to compare the current race to the best performance. Other examples include hockey puck tracking and annotations of racing car performance and snooker ball trajectories. [41][77]

AR can enhance concert and theater performances. For example, artists can allow listeners to augment their listening experience by adding their performance to that of other bands/groups of users.[78][79][80]

The gaming industry has benefited a lot from the development of this technology, a number of games have been developed for prepared indoor environments. Early AR games also include AR air hockey, collaborative combat against virtual enemies, and an AR-enhanced pool games. A significant number of games incorporate AR in it and with the introduction of smartphone this has had a bigger impact.[81][82][83]

Task support

Complex tasks such as assembly, maintenance, and surgery can be simplified by inserting additional information into the field of view. For example, labels can be displayed on parts of a system to clarify operating instructions for a mechanic who is performing maintenance on the system.[84][85] Assembly lines gain many benefits from the usage of AR. In addition to Boeing, BMW and Volkswagen are known for incorporating this technology in their assembly line to improve their manufacturing and assembly processes.[86][87][88]Big machines are difficult to maintain because of the multiple layers or structures they have. With the use of AR the workers can complete their job in a much easier way because AR permits them to look through the machine as if it was with x-ray, pointing them to the problem right away.[89]

Tourism and sightseeing

Augmented reality is used in applications for tourism, including highlighting information of important places and providing connections between the real world and historic events, such as rendering historical events into a view of a current landscape.[90] [91] [92] The use of AR in this area has enhanced the experience of users when they go traveling by providing information of the place they are at as well as comments made by other users that have been there before. AR in the tourism industry can connect with different platforms to provide a richer experience to the final user of the system.[93]

Translation

AR systems can provide dynamic subtitles in the user's language.[94][95]

Notable researchers

- Ivan Sutherland invented the first AR head-mounted display at Harvard University.
- Steven Feiner, Professor at Columbia University, is a leading pioneer of augmented reality, and author of the first paper on an AR system prototype, KARMA (the Knowledge-based Augmented Reality Maintenance Assistant), along with Blair MacIntyre and Doree Seligmann.[96]
- L.B. Rosenberg developed one of the first known AR systems, called Virtual Fixtures, while working at the U.S. Air Force Armstrong Labs in 1991, and published first study of how an AR system can enhance human performance.[97]
- Dieter Schmalstieg and Daniel Wagner jump started the field of AR on mobile phones. They developed the first marker tracking systems for mobile phones and PDAs.[98]
- Bruce H. Thomas and Wayne Piekarski develop the Tinmith system in 1998.[99] They along with Steve Feiner with his MARS system pioneer outdoor augmented reality.
- Reinhold Behringer performed important early work in image registration for augmented reality, and prototype wearable testbeds for augmented reality. He also co-organized the First IEEE International Symposium on Augmented Reality in 1998 (IWAR'98), and co-edited one of the first books on augmented reality.[100][101][102]

History

- 1901: L. Frank Baum, an author, first mentions the idea of an electronic display/spectacles that overlays data onto real life (in this case 'people'), it's named a 'character marker'.[103]
- 1957–62: Morton Heilig, a cinematographer, creates and patents a simulator called Sensorama with visuals, sound, vibration, and smell.[104]
- 1966: Ivan Sutherland invents the head-mounted display and positions it as a window into a virtual world.
- 1975: Myron Krueger creates Videoplace to allow users to interact with virtual objects for the first time.
- 1989: Jaron Lanier coins the phrase Virtual Reality and creates the first commercial business around virtual worlds.
- 1992: L.B. Rosenberg develops one of the first functioning AR systems, called Virtual Fixtures, at the U.S. Air Force Research Laboratory—Armstrong, and demonstrates benefits to human performance.[97][105]
- 1992: Steven Feiner, Blair MacIntyre and Doree Seligmann present the first major paper on an AR system prototype, KARMA, at the Graphics Interface conference.
- 1993 A widely cited version of the paper above is published in Communications of the ACM - Special issue on computer augmented environments, edited by Pierre Wellner, Wendy Mackay, and Rich Gold.[106]
- 1993: Loral WDL, with sponsorship from STRICOM, performed the first demonstration combining live AR-equipped vehicles and manned simulators. Unpublished paper, J. Barrilleaux, "Experiences and Observations in Applying Augmented Reality to Live Training", 1999.[107]
- 1994: Julie Martin creates first 'Augmented Reality Theater production', Dancing In Cyberspace, funded by the Australia Council for the Arts, features dancers and acrobats manipulating body–sized virtual object in real time, projected into the same physical space and performance plane. The acrobats appeared immersed within the virtual object and environments. The installation used Silicon Graphics computers and Polhemus sensing system.
- 1998: Spatial Augmented Reality introduced at University of North Carolina at Chapel Hill by Raskar, Welch, Fuchs.[29]
- 1999: Hirokazu Kato (加藤博一) created ARToolKit at HITLab, where AR later was further developed by other HITLab scientists, demonstrating it at SIGGRAPH.

- 2000: Bruce H. Thomas develops ARQuake, the first outdoor mobile AR game, demonstrating it in the International Symposium on Wearable Computers.
- 2008: Wikitude AR Travel Guide launches on 20 Oct 2008 with the G1 Android phone.[108]
- 2009: ARToolkit was ported to Adobe Flash (FLARToolkit) by Saqoosha, bringing augmented reality to the web browser.[109]
- 2009: project SixthSense from MIT showcased projection based wearable AR pendent device.[110]
- 2011 : LASTER Technologies, a French start-up from University of Paris Sud (Orsay), has developed first augmented reality ski goggle in the market, demonstrating it at SIGGRAPH.[111]

References

[1] Graham, M., Zook, M., and Boulton, A. "Augmented reality in urban places: contested content and the duplicity of code." (http://onlinelibrary.wiley.com/doi/10.1111/j.1475-5661.2012.00539.x/abstract) Transactions of the Institute of British Geographers, DOI: 10.1111/j.1475-5661.2012.00539.x 2012

[2] Steuer, Jonathan. Defining Virtual Reality: Dimensions Determining Telepresence (http://ww.cybertherapy.info/pages/telepresence.pdf), Department of Communication, Stanford University. 15 October 1993

[3] Introducing Virtual Environments (http://archive.ncsa.illinois.edu/Cyberia/VETopLevels/VR.Overview.html) National Center for Supercomputing Applications, University of Illinois

[4] Chen, Brian X. If You're Not Seeing Data, You're Not Seeing (http://www.wired.com/gadgetlab/tag/augmented-reality/), *Wired*, 25 August 2009

[5] Maxwell, Kerry. Augmented Reality (http://www.macmillandictionary.com/buzzword/entries/augmented-reality.html), *Macmillan Dictionary Buzzword*

[6] Augmented reality-Everything about AR (http://www.augmentedrealityon.com/), *Augmented Reality On*

[7] Azuma, Ronald. *A Survey of Augmented Reality* (http://www.cs.unc.edu/~azuma/ARpresence.pdf) Presence: Teleoperators and Virtual Environments, pp. 355–385, August 1997.

[8] Rolland, Jannick P; Holloway, Rich;Fuchs, Henry; A comparison of optical and video see-through head-mounted displays (http://www.creol.ucf.edu/Research/Publications/1505.PDF) Department of Computer Science, University of North Carolina

[9] Boger, Yuval. Virtual reality and head-mounted displays (http://vrguy.blogspot.com/2008/02/optical-see-through-vs-video-see.html) *VRGuy* 21 February 2008

[10] Fuchs, Henry; Ackerman, Jeremy. Displays for Augmented Reality: Historical Remarks and Future Prospects (http://www.cs.unc.edu/~fuchs/publications/DisplaysforAR99.pdf),Proceedings of 1st International Symposium on Mixed Reality (ISMR'99), Yokohama, Japan, pp. 31-40, (1999)

[11] Kiyokawa, Kiyoshi; Ohno, Hiroyuk; Yoshinori, Kurata An Optical See-Through Display for Mutual Occlusion of Real and Virtual Environments (http://graphics.cs.columbia.edu/courses/mobwear/resources/kiyokawa-isar00.pdf), Columbia University

[12] Fleet Week: Office of Naval Research Technology - Virtual Reality Welder Training (http://www.eweek.com/c/a/Security/Fleet-Week-Office-of-Naval-Research-Technology/4/), *eweek*, 28 May 2012

[13] Rolland, Jannick; Baillott, Yohan; Goon, Alexei. A Survey of Tracking Technology for Virtual Envirinments (ftp://ftp.cis.upenn.edu/pub/cg/public_html/research/AF/papers/tracking-chapter.pdf), Center for Research and Education in Optics and Lasers, University of Central Florida

[14] Flatley, Joseph. Lockheed Martin and Microvision developing wearable displays for DARPA (http://www.engadget.com/2009/07/07/lockheed-martin-and-microvision-developing-wearable-displays-for/). *engadget* 7 July 2009

[15] Ingram, David; Newman, Joseph. Augmented Reality (http://www.cl.cam.ac.uk/research/dtg/attarchive/ar/) Cambridge University Computer Laboratory

[16] Saenz, Aaron. Retail Head Mounted Displays Getting Better (http://singularityhub.com/2010/01/06/retail-head-mounted-displays-getting-better-vuzix-wrap-920/). *Singularity Hub*, 6 January 2010.

[17] Genuth, Ido; Raz, Barak Lumus - Future Video-Eyeglasses (http://thefutureofthings.com/articles/54/lumus-future-video-eyeglasses.html). *The Future of Things* 17 July 2007

[18] Laloum, Boris; Agnola, Michel. LASTER Technologies Announces the Compatibility of Its Augmented Reality Glasses (http://www.businesswire.com/news/home/20120808005857/en/LASTER-Technologies-Announces-Compatibility-Augmented-Reality-Glasses). *BusinessWire* 8 August 2012

[19] Klepper, Sebastian. Augmented Reality - Display Systems (http://campar.in.tum.de/twiki/pub/Chair/TeachingSs07ArProseminar/1_Display-Systems_Klepper_Report.pdf)

[20] Bilton, Nick (22 February 2012). "Behind the Google Goggles, Virtual Reality" (http://www.nytimes.com/2012/02/23/technology/google-glasses-will-be-powered-by-android.html). *The New York Times*. . Retrieved 2012-02-23., New York Times.

[21] Gannes, Liz. "Google Unveils Project Glass: Wearable Augmented-Reality Glasses" (http://allthingsd.com/20120404/google-unveils-project-glass-wearable-augmented-reality-glasses/). . Retrieved 2012-04-04., All Things D.

[22] Marker vs Markerless AR (http://researchguides.dartmouth.edu/content.php?pid=227212&sid=1891183), Dartmouth College Library

[23] Feiner, Steve. "Augmented reality: a long way off?" (http://www.pocket-lint.com/news/38869/augmented-reality-interview-steve-feiner). *AR Week*. Pocket-lint. . Retrieved 3 March 2011.

[24] Bimber, Oliver; Raskar, Ramish. "Spatial augmented reality : merging real and virtual worlds" (https://akela.mendelu.cz/~xkoubek0/VRUT/Spatial_Augmented_Reality.pdf). AK Peters (2005). .

[25] Milgram, Paul ; Takemura, Haruo; Utsumi, Akira; Kishino, Utsumi; Kishino, Kishin. Augmented Reality: A class of displays on the reality-virtuality continuum (http://etclab.mie.utoronto.ca/publication/1994/Milgram_Takemura_SPIE1994.pdf), *Telemanipulator and Telepresence Technologies*, SPIE **2351** p. 282-292

[26] Bimber, Oliver; Encarnação, Miguel; Branco, Pedro. The Extended Virtual Table: An Optical Extension for Table-Like Projection Systems (http://www.mitpressjournals.org/doi/abs/10.1162/105474601753272862?journalCode=pres), *MIT Press Journal* Vol. 10, No. 6, Pages 613-631, March 13, 2006

[27] Mahoney, Diana Phillips. [Showcasing Augmented Reality (http://www.cgw.com/Publications/CGW/2001/Volume-24-Issue-11-November-2001-/Showcasing-Augmented-Reality.aspx) *Computer Graphics World* Vol: 24 Issue: 11 (November 2001)

[28] Bimber, O.; Fröhlich, B.; Schmalstieg, D.; Encarnacao, L.M. The virtual showcase (http://publica.fraunhofer.de/documents/N-7978.html) *IEEE Computer Graphics and Applications* vol. 21 No.6, pp.48-55 (2001)

[29] Ramesh Raskar, Greg Welch, Henry Fuchs Spatially Augmented Reality (http://www.cs.unc.edu/~raskar/Office), First International Workshop on Augmented Reality, Sept 1998

[30] David Drascic of the University of Toronto is a developer of ARGOS: A Display System for Augmenting Reality (http://vered.rose.utoronto.ca/people/david_dir/CHI93/CHI93.full.html). David also has a number of AR related papers on line, accessible from his home page (http://vered.rose.utoronto.ca/people/David.html).

[31] Augmented reality brings maps to life (http://www.newscientist.com/article/dn7695) 19 July 2005

[32] Feiner, Steve. "Augmented reality: a long way off?" (http://www.pocket-lint.com/news/38802/augmented-reality-maintenance-and-repair). *AR Week*. Pocket-lint.com. Archived (http://web.archive.org/web/20110306103947/http://www.pocket-lint.com/news/38802/augmented-reality-maintenance-and-repair) from the original on 6 March 2011. . Retrieved 3 March 2011.

[33] Stationary systems can employ 6DOF track systems such as Polhemus, ViCON, A.R.T, or Ascension.

[34] Piekarski, W.; Thomas, B.H. Glove Based User Interaction Techniques for Augmented Reality in an Outdoor Environment (http://gestaction.troulite.fr/publis/thomas02glove.pdf)

[35] Parr, ben. One step closer to Minority Report: The wireless glove mouse (http://mashable.com/2010/04/02/wireless-glove-mouse/) *Mashable Tech* 2 April 2010

[36] Strange, Adario. Canon visor and wand gives you control of augmented reality (http://dvice.com/archives/2012/06/canon-mixed-rea.php). 'DVICE *20 June 2012*

[37] Hand, Randall. Sony's Wand Controller & Augmented Reality Gaming (http://www.vizworld.com/2009/07/sonys-wand-controller-augmented-reality-gaming/) *VizWorld* 13 July 2009

[38] Marshall, Gary. Beyond the mouse: how input is evolving, Touch,voice and gesture recognition and augmented reality (http://www.techradar.com/news/computing/beyond-the-mouse-how-input-is-evolving-626794?artc_pg=1) *techradar.computing\PC Plus* 23 August 2009

[39] Chaves, Thiago; Figueiredo, Lucas; Da Gama, Alana; de Araujo, Christiano; Teichrieb, Veronica. Human Body Motion and Gestures Recognition Based on Checkpoints (http://dl.acm.org/citation.cfm?id=2377147). SVR '12 Proceedings of the 2012 14th Symposium on Virtual and Augmented Reality Pages 271-278

[40] Barrie, Peter; Komninos, Andreas; Mandrychenko, Oleksii. A Pervasive Gesture-Driven Augmented Reality Prototype using Wireless Sensor Body Area Networks (http://www.buccleuchpark.net/MUCOM/publi/acmMobility09.pdf)

[41] Azuma, Ronald; Balliot, Yohan; Behringer, Reinhold; Feiner, Steven; Julier, Simon; MacIntyre, Blair. Recent Advances in Augmented Reality (http://www.cc.gatech.edu/~blair/papers/ARsurveyCGA.pdf) *Computers & Graphics*, November 2001

[42] Maida, James; Bowen, Charles; Montpool, Andrew; Pace, John. Dynamic registration correction in augmented-reality systems (http://research.jsc.nasa.gov/PDF/SLiSci-14.pdf), *Space Life Sciences*, NASA

[43] State, Andrei; Hirota, Gentaro; Chen,David T; Garrett, William; Livingston, Mark. Superior Augmented Reality Registration by Integrating Landmark Tracking and Magnetic Tracking (http://www.cs.princeton.edu/courses/archive/fall01/cs597d/papers/state96.pdf), Department of Computer ScienceUniversity of North Carolina at Chapel Hill

[44] Bajura, Michael; Neumann, Ulrich. Dynamic Registration Correction in Augmented-Reality Systems (http://graphics.usc.edu/cgit/publications/papers/DynamicRegistrationVRAIS95.pdf) University of North Carolina, University of Southern California

[45] Augmented Reality Landscape (http://augmentedrealitybiz.com/augmented-reality-landscape/) 11 August 2012

[46] Stuart Eve. "Augmenting Phenomenology: Using Augmented Reality to Aid Archaeological Phenomenology in the Landscape." (http://dx.doi.org/10.1007/s10816-012-9142-7). . Retrieved 2012-09-25.

[47] Dähne, Patrick; Karigiannis, John N.. "Archeoguide: System Architecture of a Mobile Outdoor Augmented Reality System" (http://portal.acm.org/citation.cfm?id=854948). . Retrieved 2010-01-06.

[48] Anish Tripathi. "Augmented Reality: An Application for Architecture" (http://www.usc.edu/dept/architecture/mbs/thesis/anish/). . Retrieved 2010-01-06.

[49] Lieberman, Zachary. "The Eyewriter" (http://www.eyewriter.org/). . Retrieved 2010-04-27.

[50] Wood, Tom. "Kudan Augmented Art" (http://kudan.eu/portfolio/liesje-reyskens-photography/). . Retrieved 2012-08-01.

[51] Lego using AR for commercial purposes (http://www.geek.com/articles/geek-cetera/lego-augmented-reality-kiosks-heading-to-shops-worldwide-20100419/). Geek.com (19 April 2010). Retrieved 9 June 2012.
[52] Fawkes, Piers. (2011-08-12) Disney's AR mirror (http://www.psfk.com/2011/08/mirror-lets-kids-try-on-virtual-outfits.html). Psfk.com. Retrieved 9 June 2012.
[53] (http://fashionablymarketing.me/2012/08/zugara-launches-worlds-1st-augmented-reality-ecommerce-platform-module) FMM.com. Retrieved 4 August 2012.
[54] Nissan website (http://www.nissanusa.com/cube/). Nissanusa.com. Retrieved 9 June 2012.
[55] Vlad Savov. "Best Buy goes 3D, even augmented reality isn't safe from advertising" (http://www.engadget.com/2009/08/06/best-buy-goes-3d-even-augmented-reality-isnt-safe-from-adverti). .
[56] AR at Disney (http://adsoftheworld.com/media/outdoor/walt_disney_prince_of_persia_the_gods_have_a_plan_for_you). Adsoftheworld.com. Retrieved 9 June 2012.
[57] "Futuristic Super 8 Ads Remind Us of Minority Report" (http://www.pcworld.com/article/230118/futuristic_super_8_ads_remind_us_of_minority_report.html). PC World. .
[58] Alexander, Michael. Arbua Shoco Owl Silver Coin with Augmented Reality (http://news.coinupdate.com/arbua-shoco-owl-silver-coin-with-augmented-reality-1490/), *Coin Update* July 20, 2012
[59] Royal Mint produces revolutionary commemorative coin for Aruba (http://www.todaysxm.com/2012/08/07/royal-mint-produces-revolutionary-commemorative-coin-for-aruba/), *Today* Augist 7, 2012
[60] Groundbreaking Augmented Reality-Based Reading Curriculum Launches (http://www.prweb.com/releases/2011/10/prweb8899908.htm), ''PRweb'', 23 October 2011
[61] Stewart-Smith, Hanna. Education with Augmented Reality: AR textbooks released in Japan (http://www.zdnet.com/blog/asia/education-with-augmented-reality-ar-textbooks-released-in-japan-video/1541), ''ZDnet'', 4 April 2012
[62] Augmented reality in education (http://smarterlearning.wordpress.com/2011/11/10/augmented-reality-in-education/) *smarter learning*
[63] Lebrecht, Anna. Augmented Reality for Education (http://digitalunion.osu.edu/2012/04/24/augmented-reality-for-education/) ''Digital Union'', The Ohio State University 24 April 2012
[64] Kaufmann, Hannes. Collaborative Augmented Reality in Education (http://www.ita.mx/files/avisos-desplegados/ingles-tecnico/guias-estudio-abril-2012/articulo-informatica-1.pdf), Institute of Software Technology and Interactive Systems, Vienna University of Technology
[65] Noelle, S. (2002). "Stereo augmentation of simulation results on a projection wall" (http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=1115108&tag=1). *Mixed and Augmented Reality, 2002. ISMAR 2002. Proceedings.*: 271-322. . Retrieved 7 October 2012.
[66] Verlinden, Jouke; Horvath, Imre. *Augmented Prototyping as Design Means in Industrial Design Engineering* (http://www.io.tudelft.nl/index.php?id=24954&L=1). Delft University of Technology. . Retrieved 7 October 2012.
[67] Pang, Y; Nee, A; Youcef-Toumie, Kamal; Ong, S.K; Yuan, M.L (November, 18 2004). *Assembly Design and Evaluation in an Augmented Reality Environment* (http://dspace.mit.edu/bitstream/handle/1721.1/7441/IMST?sequence=1). National University of Singapore, M.I.T.. . Retrieved 7 October 2012.
[68] Mountney, Peter; Giannarou, Stamatia ; Elson, Daniel; Yang, Guang-Zhong. Optical Biopsy Mapping for Minimally Invasive Cancer Screening. (http://www.ncbi.nlm.nih.gov/pubmed/20426023) Department of Computing, Imperial College 2009
[69] "UNC Ultrasound/Medical Augmented Reality Research" (http://www.cs.unc.edu/Research/us/). Archived (http://web.archive.org/web/20100212231230/http://www.cs.unc.edu/Research/us/) from the original on 12 February 2010. . Retrieved 2010-01-06.
[70] Cameron, Chris. Military-Grade Augmented Reality Could Redefine Modern Warfare (http://www.readwriteweb.com/archives/military_grade_augmented_reality_could_redefine_modern_warfare.php) *ReadWriteWeb* June 11, 2010
[71] Tönnis, M, Sandor, C, Klinker, G, Lange, C and Bubb, H. Experimental evaluation of an augmented reality visualization for directing a car driver‟s attention. In ISMAR'05: Proc. 4th Int'l Symp. on Mixed and Augmented Reality, Vienna, Austria, 5–8 Oct. 2005. IEEE CS Press, pp. 56–59
[72] GM's Enhanced Vision System (http://techcrunch.com/2010/03/17/gms-enhanced-vision-system-brings-augmented-reality-to-vehicle-huds/). Techcrunch.com (17 March 2010). Retrieved 9 June 2012.
[73] Cheney-Peters, Scott (12 April 2012). "CIMSEC: Google's AR Goggles" (http://cimsec.org/bridgegoggles/). . Retrieved 2012-04-20.
[74] Stafford, Aaron; Piekarski, Wayne; Thomas, Bruce H.. "Hand of God" (http://www.hog3d.net/). Archived (http://web.archive.org/web/20091207022651/http://www.hog3d.net/) from the original on 7 December 2009. . Retrieved 2009-12-18.
[75] Benford, S, Greenhalgh, C, Reynard, G, Brown, C and Koleva, B. Understanding and constructing shared spaces with mixed-reality boundaries. ACM Trans. Computer-Human Interaction, 5(3):185–223, Sep. 1998
[76] Office of Tomorrow (http://mi-lab.org/projects/office-of-tomorrow/) *Media Interaction Lab*
[77] Marlow, Chris. Hey, hockey puck! NHL PrePlay adds a second-screen experience to live games (http://www.dmwmedia.com/news/2012/04/27/hey-hockey-puck-nhl-preplay-adds-a-second-screen-experience-to-live-games), *digitalmediawire* April 27, 2012
[78] Pair, J.; Wilson, J.; Chastine, J.; Gandy, M. " The Duran Duran Project: The Augmented Reality Toolkit in Live Performance (http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?tp=&arnumber=1107010)". *The First IEEE International Augmented Reality Toolkit Workshop*, 2002
[79] Broughall, Nick. Sydney Band Uses Augmented Reality For Video Clip. (http://www.gizmodo.com.au/2009/10/sydney-band-uses-augmented-reality-for-video-clip/) *Gizmodo*, 19 October 2009

[80] Pendlebury, Ty. Augmented reality in Aussie film clip (http://www.cnet.com.au/augmented-reality-in-aussie-film-clip-339299097.htm). *c|net* 19 October 2009
[81] Hawkins, Mathew. Augmented Reality Used To Enhance Both Pool And Air Hockey (http://www.gamesetwatch.com/2011/10/augmented_reality_used_to_enhance_both_pool_and_air_hockey.php) *Game Set Watch*October 15, 2011
[82] One Week Only - Augmented Reality Project (http://combathelo.blogspot.com/2012/07/one-week-only-augmented-reality-project.html) *Combat-HELO Dev Blog* July 31, 2012
[83] What Are the Different Types of Augmented Reality Apps? (http://www.wisegeek.com/what-are-the-different-types-of-augmented-reality-apps.htm) *wiseGeek*
[84] The big idea:Augmented Reality (http://ngm.nationalgeographic.com/big-idea/14/augmented-reality-pg1). Ngm.nationalgeographic.com (15 May 2012). Retrieved 9 June 2012.
[85] Henderson, Steve; Feiner, Steven. "Augmented Reality for Maintenance and Repair (ARMAR)" (http://graphics.cs.columbia.edu/projects/armar/). . Retrieved 2010-01-06.
[86] Sandgren, Jeffrey. The Augmented Eye of the Beholder (http://brandtechnews.net/tag/augmented-reality/), *BrandTech News* January 8, 2011
[87] Cameron, Chris. Augmented Reality for Marketers and Developers (http://www.slideshare.net/readwriteweb/augmented-reality-for-marketers-and-developers-analysis-of-the-leaders-the-challenges-and-the-future), *ReadWriteWeb*
[88] Dillow, Clay BMW Augmented Reality Glasses Help Average Joes Make Repairs (http://www.popsci.com/scitech/article/2009-09/bmw-developing-augmented-reality-help-mechanics), *Popular Science* September 2009
[89] King, Rachael. Augmented Reality Goes Mobile (http://www.businessweek.com/stories/2009-11-03/augmented-reality-goes-mobilebusinessweek-business-news-stock-market-and-financial-advice), *Bloomberg Business Week Technology* November 3, 2009
[90] Saenz, Aaron Augmented Reality Does Time Travel Tourism (http://singularityhub.com/2009/11/19/augmented-reality-does-time-travel-tourism/) *SingularityHUB* NOvember 19, 2009
[91] Sung, Dan Augmented reality in action - travel and tourism (http://www.pocket-lint.com/news/38806/augmented-reality-travel-tourism-apps) *Pocket-lint* March 2, 2011
[92] Dawson, Jim Augmented Reality Reveals History to Tourists (http://www.livescience.com/5644-augmented-reality-reveals-history-tourists.html) *Life Science* August 16, 2009
[93] Bartie, P and Mackaness, W. Development of a speech-based augmented reality system to support exploration of cityscape. (http://onlinelibrary.wiley.com/doi/10.1111/j.1467-9671.2006.00244.x/abstract) Trans. GIS, 10(1):63–86, 2006
[94] Tsotsis, Alexia. Word Lens Translates Words Inside of Images. Yes Really. (http://techcrunch.com/2010/12/16/world-lens-translates-words-inside-of-images-yes-really) *TechCrunch* (16 December 2010)
[95] N.B. Word Lens: This changes everything (http://www.economist.com/blogs/gulliver/2010/12/instant_translation) *The Economist: Gulliver blog* 18 December 2010
[96] "Knowledge-based augmented reality" (http://portal.acm.org/citation.cfm?id=159587). ACM. July, 1993. .
[97] L. B. Rosenberg. The Use of Virtual Fixtures As Perceptual Overlays to Enhance Operator Performance in Remote Environments. Technical Report AL-TR-0089, USAF Armstrong Laboratory, Wright-Patterson AFB OH, 1992.
[98] Wagner, Daniel (29 September 2009). "First Steps Towards Handheld Augmented Reality" (http://portal.acm.org/citation.cfm?id=946910). ACM. . Retrieved 2009-09-29.
[99] Piekarski, William; Thomas, Bruce. Tinmith-Metro: New Outdoor Techniques for Creating City Models with an Augmented Reality Wearable Computer (http://www.computer.org/portal/web/csdl/doi/10.1109/ISWC.2001.962093) Fifth International Symposium on Wearable Computers (ISWC'01), 2001 pp.31
[100] Behringer, R.;[http://reference.kfupm.edu.sa/content/i/m/improving_the_registration_precision_by__1670204.pdf Improving the Registration Precision by Visual Horizon Silhouette Matching.] Rockwell Science Center
[101] Behringer, R.;Tam, C; McGee, J.; Sundareswaran, V.; Vassiliou, Marius. Two Wearable Testbeds for Augmented Reality: itWARNS and WIMMIS. (http://www.computer.org/portal/web/csdl/doi/10.1109/ISWC.2000.888495) ISWC 2000, Atlanta, 16–17 October 2000.
[102] R. Behringer, G. Klinker,. D. Mizell. Augmented Reality – Placing Artificial Objects in Real Scenes (http://www.crcpress.com/product/isbn/9781568810980). Proceedings of IWAR '98. A.K.Peters, Natick, 1999. ISBN 1-56881-098-9
[103] Johnson, Joel. “The Master Key”: L. Frank Baum envisions augmented reality glasses in 1901 (http://moteandbeam.net/the-master-key-l-frank-baum-envisions-ar-glasses-in-1901) *Mote & Beam* 10 September 2012
[104] http://www.google.com/patents?q=3050870
[105] L. B. Rosenberg, "The Use of Virtual Fixtures to Enhance Operator Performance in Telepresence Environments" SPIE Telemanipulator Technology, 1993.
[106] Wellner, Pierre. "Computer Augmented Environments: back to the real world" (http://dl.acm.org/citation.cfm?id=159544). ACM. . Retrieved 28 July 2012.
[107] Barrilleaux, Jon. Experiences and Observations in Applying Augmented Reality to Live Training (http://jmbaai.com/vwsim99/vwsim99.html). Jmbaai.com. Retrieved 9 June 2012.
[108] Wikitude AR Travel Guide (http://www.youtube.com/watch?v=8EA8xlicmT8). Youtube.com. Retrieved 9 June 2012.
[109] Cameron, Chris. [Flash-based AR Gets High-Quality Markerless Upgrade], *ReadWriteWeb* 9 July 2010

[110] Boyd, Clark. BBC (http://news.bbc.co.uk/1/hi/technology/7997961.stm) SixthSense blurs digital and the real. *BBC News*, 14 April 2009
[111] Separa , Jason; Kawano, Gregory. Augmented Reality (http://www.csulb.edu/~hill/ee400d/Reference Folder/AugmentedReality.pdf), California State University, Long Beach

External links

Augmented reality (http://www.dmoz.org/Computers/Virtual_Reality/) at the Open Directory Project

List of emerging technologies

This is a **list of currently emerging technologies**, which contains some of the most prominent ongoing developments, advances, and innovations in various fields of modern technology. Emerging technologies are those technical innovations which represent progressive developments within a field for competitive advantage.[1]

Agriculture

Emerging technology	Status	Potentially marginalized technologies	Potential applications	Related articles
Agricultural robot	Research and development, trial projects			
Closed ecological systems	Research and development, working demonstrators (e.g. Biosphere 2)	Agricultural science	Agriculture, scientific research, space colonization	Greenhouse, Eden Project, Bioshelter, Seawater greenhouse, Perpetual harvest greenhouse system
Genetically modified food	Research and development, commercialization			
In vitro meat	Research and development, non-profit organization New Harvest set up to promote development[2][3][4]	Animal husbandry, livestock, poultry, fishing[4]	Cruelty free, inexpensive and environmentally friendlier meat to consume[4]	
Precision agriculture	Research and development, diffusion			
Vertical farming	Research and experiments[5][6]	Industrial agriculture	Crop and meat production	

Biomedical

Emerging technology	Status	Potentially marginalized technologies and/or industries	Potential applications	Related articles
Artificial uterus	Theory, research	Incubator		
Body implants, prosthesis	Trials, from animal (e.g., brain implants) to human clinical (e.g., insulin pump implant), to commercial production (e.g. pacemaker, joint replacement, cochlear implant)	Various fields of medicine	Brain implant, retinal implant	Prosthetics, prosthetics in fiction
Cryonics	Theory, research			
Genetic engineering	Research, development, commercialization[7][8]	Animal husbandry, plant breeding	Creating and modifying species, bio-machines, eliminating genetic disorders (gene therapy)	Genetically modified food, genetic pollution
Head transplant, isolated brain	Theory, research[9][10][11]			Brain transplant
Hibernation or suspended animation	Research, development, animal trials[12]	Surgical anesthesia	Organ transplantation, space travel, prolonged surgery, emergency care	
Life extension, Strategies for Engineered Negligible Senescence	Research, experiments, animal testing[13][14][15]	Existing treatments for age-related diseases[15]	Increased life spans[15]	Resveratrol, SRT1720
Nanomedicines	Research, experiments, limited use[16][17]			
Personalized medicine, full genome sequencing	Research, experiments[18]	Orphan drugs	Cancer management and preventive treatment; genetic disorders	
Regenerative medicine	Some laboratory trials[19]		Life extension	
Robotic surgery	Research, diffusion[20][21][22]	Surgeons untrained in robotic surgery		
Stem cell treatments	Research, experiments, phase I human trial spinal cord injury treatment (GERON), cultured cornea transplants[23][24]	Other therapies	Treatment for a wide range of diseases and injuries	Stem cell, stem cell treatments, Skin cell gun
Tissue engineering	Research, diffusion[25][26][27][28]		Organ printing	
Vitrification or cryoprotectant	Theory, some experiments[29]	Ischemic damages	Organ transplantation, cryonics	

Displays

Emerging technology	Status	Potentially marginalized technologies	Potential applications	Related articles
3D displays	Research, commercialization[30][31]	other display technologies, CRT, LCD	Television, computer interfaces, cinemas	Autostereoscopic display, stereoscopic display, volumetric display, holographic display, Light Field display, Nintendo 3DS, HTC Evo 3D
Ferro Liquid Display	Some commercial products			
OLED displays	Diffusion[32][33]	LCD and plasma displays	Displays, lighting	OLED TV, Comparison of display technology
Organic light-emitting transistor	Development			
Interferometric modulator display	Development, commercializing[34]	Other display technologies, CRT, LCD, plasma, e-paper	Non-emissive displays with fast response times and potentially the most realistic colors of all display technologies	Interferometric modulator display, comparison of display technology
Time-multiplexed optical shutter	Commercialized			
Laser video displays	first commercial Laser TV in 2008, Mitsubishi LaserVue TV	LCD and plasma displays	Displays with very wide colour gamut prowess	Laser TV, Comparison of display technology Next generation of display technology
Screenless display (Virtual retinal display, Bionic contact lens), EyeTap	Theory, experiments[35]	Traditional displays	Augmented reality, virtual reality, EyeTap could allow the user to reference the blue prints like in a construction yard, in a 3D manner, Delivers the user constant up to date information on the stock market, the user's corporation, and meeting statuses, visual disabilities	Head-mounted display, Head-up display, adaptive optics
Telescopic pixel display	In development			
Phased-array optics	Theory[36][37]	Conventional display devices (e.g., television)	Mass production of 3-dimensional imagery	
Thick-film dielectric electroluminescent technology	Suspended			
Holography (Holographic display, Computer-generated holography)	Diffusion[38][39][40]	Display technologies		
Quantum dot display	Diffusion			
Surface-conduction electron-emitter display	Abandoned	Traditional displays	Displays with high contrast ratio, fast response time and high energy efficiency	
Field emission display	Research			
Volumetric display			3-dimensional imagery	Swept-volume display

Electronics

Emerging technology	Status	Potentially marginalized technologies	Potential applications	Related articles
Electronic nose	Research, commercialization[41][42]	X-ray and MRI scans for detecting cancer	Detecting spoiled food, chemical weapons and cancer	
E-textiles	Research, diffusion[43]			
Flexible electronics	Research, development, some prototypes[44][45]		Flexible and folding electronic devices (such as smartphones), Flexible solar cells which are lightweight, can be rolled up for launch, and are easily deployable	Nokia Morph, Flexible organic light-emitting diode
Memristor	Working prototype[46][47]	Some current integrated circuits, many other electronics devices	Smaller, faster, lower power consuming storage, analogue electronics, Artificial intelligence	
Spintronics	Working prototypes[48]	Mechanical magnetic hard disk drives	Data storage	MRAM
Thermal copper pillar bump	Working prototypes in discrete devices	Conventional thermal systems, heat sinks, bulk thermoelectrics	Electric circuit cooling; micro-fluidic actuators; small-device thermoelectric power generation	Ultra high definition holographic disc, Metal–insulator transition

Energy

Emerging technology	Status	Potentially marginalized technologies	Potential applications	Related articles
Airborne wind turbine	Research[49][50][51]	Fossil fuels	Producing electricity	KiteGen
Flywheel energy storage	Some commercial examples			
Artificial photosynthesis	Research, experiments[52]		replicate the natural process of photosynthesis, converting sunlight, water, carbon dioxide into carbohydrates and oxygen	AlgaePARC
Biofuels	Diffusion[53]	Fossil fuels	Energy storage, more so for transport	Issues relating to biofuels
Concentrated solar power	Growing markets in California, Spain, Northern Africa[54]	Fossil fuels, photovoltaics	Producing electricity	DESERTEC, BrightSource Energy, Solar Millennium
Electric double-layer capacitor	Diffusion, continued development[55]	Chemical batteries	Regenerative braking; energy storage: generally faster charging, longer lasting, more flexible, greener	
Fusion power	Theory, experiments; for 60+ years[56]	Fossil fuels, renewable energy, nuclear fission power	Producing electricity, heat, fusion torch recycling with waste heat	ITER, NIF, Polywell, Dense plasma focus, Muon-catalyzed fusion
Grid energy storage	Increasing use			

Silicon–air battery	Experiments			
Generation IV reactor	Research, Experiments	Traditional nuclear power reactors, fossil fuels	Producing electricity, heat, transmutation of nuclear waste stockpiles from traditional reactors	Plasma arc waste disposal
Home fuel cell	Research, commercialisation[57][58][59]	Electrical grid	Off-the-grid, producing electricity	Autonomous building, Bloom Energy Server
Hydrogen economy	Diffusion of hydrogen fuel cells; theory, experiments for lower cost hydrogen production[60]	Other energy storage methods: chemical batteries, fossil fuels	Energy storage	
Lithium-air battery	Research, experiments[61]	Other energy storage methods: hydrogen, chemical batteries, some uses of fossil fuels	Laptops, mobile phones, long-range electric cars; storing energy for electric grid	
Molten salt reactor	Research, Experiments	Traditional nuclear power reactors, fossil fuels	Producing electricity, heat	
Nanowire battery	Experiments, prototypes[62][63]	Other energy storage methods: hydrogen, chemical batteries, some uses of fossil fuels	Laptops, mobile phones, long-range electric cars; storing energy for electric grid	
Nantenna	Research[64][65][66]	Fossil fuels	Producing electricity	
Smart grid	Research, diffusion[67][68][69]			Smart meter, SuperSmart Grid
Solar roadway	Research[70][71][72]	Fossil fuels	Producing electricity	
Space-based solar power	Theory			
Thorium fuel cycle	Research started in the 1960's, still ongoing	Uranium based nuclear power, fossil fuels	Producing electricity, heat	
Lithium iron phosphate battery	Commercilization			
Molten salt battery	Applications and continuing research			
Wireless energy transfer	Prototypes, diffusion, short range consumer products[73]	Power cords, plugs, batteries	Wirelessly powered equipment: laptop, cell phones, electric cars, etc.	WiTricity, resonant inductive coupling

IT and communications

Emerging technology	Status	Potentially marginalized technologies	Potential applications	Related articles
4G cellular communication	First commercial LTE networks deployed in Sweden December 2009; candidate systems LTE-advanced and IEEE 802.16m (Mobile WiMAX Release 2) in development	broadband	Pervasive computing	Mobile broadband, mobile TV, Interactive TV, 3D-TV,[74] holographic cameras[74]
Ambient intelligence	Theory			
Artificial brain	Research[75]		Neurological disease's treatments, artificial intelligence	Blue Brain Project
Artificial intelligence	Theory, experiments; limited uses in specialized domains[76][77][78]	Human decision, analysis, etc.	Creating intelligent devices	Progress in artificial intelligence, technological singularity, applications of artificial intelligence
Atomtronics	Theory			
Augmented Reality	diffusion			
Cybermethodology				
Emerging memory technologies T-RAM, Z-RAM, TTRAM, CBRAM, SONOS, RRAM, Racetrack memory, NRAM, Millipede memory	In development	Current memory technologies		
Fourth-generation optical discs (3D optical data storage, Holographic data storage)	Research, prototyping[79]	All other mass storage methods/devices, magnetic tape data storage, optical data storage	Storing and archiving data previously erased for economic reasons	Holographic Disc stores Ultra HD big Electronic IT companies are interested in this technology it has bigger capacity than Blu-ray Disc 10x times more than optical storage
General-purpose computing on graphics processing units	Diffusion of non standardized methods	CPU for a few specialized uses	Order of magnitude faster processing of parallelizable algorithms	
Machine augmented cognition, exocortices	Diffusion of primitive amplifications; working prototypes of more; theory, experiments on more substantial amplification	Libraries, schools, training, pocket calculators		
Machine translation	Diffusion[80][81]	Human translation of natural languages, in areas where misunderstanding is non-critical and language is formalized	Easier and cheaper cross-cultural communication	

Machine vision	Research, prototyping, commercialization[82]	Biotic vision and perception, including humans	Biometrics, controlling processes (e.g., in driverless car, automated guided vehicle), detecting events (e.g., in visual surveillance), interaction (e.g., in human-computer interaction), robot vision	Computer vision, pattern recognition, digital image processing
Mobile collaboration	Development, commercialization[83]	Traditional video-conferencing systems	Extends the capabilities of video conferencing for use on hand-held mobile devices in real-time over secure networks. For use in diverse industries such as manufacturing, energy, healthcare.[84]	
Optical computing	Theory, experiments; some components of integrated circuits have been developed[85]	Many electronics devices, integrated circuits	Smaller, faster, lower power consuming computing	
Quantum computing	Theory, experiments,[86] commercialization[87]	Atomtronics, Electronic computing, optical computing, quantum clock	Much faster computing, for some kinds of problems, chemical modeling, new materials with programmed properties, theory of high-temperature superconductivity and superfluidity	
Quantum cryptography	Commercialization[88]		Secure communications	
Radio-frequency identification	Diffusion of high cost[89][90][91]	Barcode	Smartstores - RFID based self checkout (keeping track of all incoming and outgoing products), food packaging, smart shelves, smart carts. See: *potential uses*	
Semantic Web or *answer machine*	Theory, research	Search engines	Making the web machine-readable by annotating data on the web based on its meaning	
Speech recognition		Mechanical input devices		
Three-dimensional integrated circuit	Development, commercialization[92][93]	Conventional integrated circuit		
Virtual Reality	diffusion	Television	Entertainment, education	

Manufacturing

Emerging technology	Status	Potentially marginalized technologies	Potential applications	Related articles
3D printing	Commercial production[94][95]	Manually making prototypes, some mass production methods that lack ability for customizing	Rapidly prototyping and producing plastic objects and multi-material items, with potential to significantly customize products for individual consumers	RepRap Project, Contour Crafting, D-Shape
Claytronics	Theory, experiment	3D printing, traditional manufacturing methods and tools		
Molecular assembler	Theory, experiment	3D printing, traditional manufacturing methods and tools		Replicator (Star Trek)
Utility fog	Theory, experiment			

Materials science

Emerging technology	Status	Potentially marginalized technologies	Potential applications	Related articles
Aerogel	Theory, experiments, diffusion, early uses[96]	Traditional Insulation, Glass	Improved insulation, insulative glass if it can be made clear, sleeves for oil pipelines, aerospace, high-heat & extreme cold applications	
Conductive Polymers	Research, experiments, prototypes	Conductors	Lighter and cheaper wires, antistatic materials, organic solar cells	
Graphene	Theory, experiments, diffusion, early uses[97][98]	silicon-based integrated circuit	Components with higher strength to weight ratios, transistors that operate at higher frequency, lower cost of display screens in mobile devices, storing hydrogen for fuel cell powered cars, sensors to diagnose diseases[99]	
High-temperature superconductivity	Cryogenic receiver front-end (CRFE) RF and microwave filter systems for mobile phone base stations; prototypes in dry ice; theory and experiments for higher temperatures[100]	Copper wire, semiconductor integral circuits	No loss conductors, frictionless bearings, magnetic levitation, lossless high-capacity accumulators, electric cars, heat-free integral circuits and processors	
High-temperature superfluidity	Superfluid gyroscopes already exist but work at very low temperatures	Mechanical gyroscope	High-precision measure of gravity, navigation and maneuver devices, possible devices to emit gravitomagnetic field, frictionless mechanical devices	
Metamaterials	Theory, experiments, diffusion[101]	Classical optics	Microscopes, cameras, metamaterial cloaking, cloaking devices	
Multi-function structures[102]	Theory, experiments, some prototypes, few commercial	Composite materials mostly	Wide range, e.g., self health monitoring, self healing, morphing...	
Nanomaterials: carbon nanotubes	Theory, experiments, diffusion, early uses[103][104]	Structural steel and aluminium	Stronger, lighter materials, space elevator	Potential applications of carbon nanotubes, carbon fiber
Programmable matter	Theory, experiments[105][106]	Coatings, catalysts	Wide range, e.g., claytronics, synthetic biology	

Quantum dots	Research, experiments, prototypes[107]	LCD, LED	Quantum dot laser, future use as programmable matter in display technologies (TV, projection), optical data communications (high-speed data transmission), medicine (laser scalpel)	
Silicene				

Military

Emerging technology	Status	Potentially marginalized technologies	Potential applications	Related articles
Airborne laser	Research and development, trials	Missile defense	Tracking and destruction of tactical ballistic missiles	Advanced Tactical Laser, High Energy Liquid Laser Area Defense System
Antimatter weapon	Theory	Nuclear weapons		
Caseless ammunition	Field tests and some niche markets	Cartridges		
Directed energy weapon	Research, development, some prototypes[108]	Firearms	Warfare	
Electrolaser	Research and development	Taser		
Electromagnetic weapons	Research and development[109][110]	Firearms	Warfare	Coilgun, Railgun
Electrothermal-chemical technology	Research and development	Conventional ammunition	Tank, artillery, and close-in weapon systems	
Particle beam weapon	Research and development	Firearms	Warfare	
Plasma weapon	Research			
Pure fusion weapon	Theory			
Sonic weapon	Research and development			
Stealth technology	Research and development	Camouflage	Electronic countermeasures	Plasma stealth, Stealth aircraft, Radar-absorbent material
Vortex ring gun	Research and development	tear gas	Crowd control	

Neuroscience

Emerging technology	Status	Potentially marginalized technologies	Potential applications	Related articles
Ampakine			Enhance attention span and alertness, and facilitate learning and memory	
Artificial brain	IBM Blue Brain project			
Brain-computer interface	Research and commercialization	Video games, television, and movies	A revolution in entertainment, etc.	
Brain-reading, Neuroinformatics	Research[111][112][113]		Mind uploading, enabling individuals with brain damage to communicate[114]	
Electroencephalography	Research, diffusion[115][116]	Keyboards and other interfaces	Controlling electronic devices via brain waves	
Neuroprosthetics			Visual prosthesis, brain implant, exocortex, retinal implant	

Robotics

Emerging technology	Status	Potentially marginalized technologies	Potential applications	Related articles
Molecular nanotechnology, nanorobotics	Theory, experiments[117]	Products and parts production, retail distribution	Machines (desktop, industrial) that can make anything given the materials, cheap planetary terraforming	
Powered exoskeleton	Research, development, prototypes, diffusion, commercializing[118]	Electric wheelchairs, forklifts	Heavy lifting, paralysis, muscle related diseases, warfare, construction, care for the elderly and disabled.	LOPES (exoskeleton), ReWalk, Human Universal Load Carrier, fictional armor Iron Man's armor, Future Force Warrior
Self-reconfiguring modular robot	Theory, experiments, early prototypes	Other ways to form physical structures and machines	As a universal physical machine, SRCMR may change the way we make many physical structures and machines	Robot, swarm robotics, autonomous research robot
Swarm robotics	Theory, experiments[119]	Distributed computing, complexity in behavior by simplicity in architecture	Autonomous construction, space construction	Swarm intelligence, autonomous robotics, nanorobotics, particle swarm optimization, multi-agent systems, behavior-based robotics

Unmanned vehicle	Research and development, some diffusion	Manned vehicles, human spying	Mass surveillance, eavesdropping, Oceanography, Commercial aerial surveillance of livestock monitoring, wildfire mapping, pipeline security, home security, road patrol and anti-piracy. Domestic aerial surveillance, patrol the nation's borders, scout property, and hunt down fugitives, Oil gas and mineral exploration and production, geophysical surveys, geomagnetic surveys, transport of goods, Scientific research in areas to dangerous for pilots like a droid hurricane tornado hunter, Armed attack, Search and rescue, explosives and Bomb disposal, peacekeeping operations, ground surveillance, gatekeeper/checkpoint operations, urban street presence, enhance police and military raids in urban settings.	Unmanned aerial vehicle, AeroVironment, AeroVironment Global Observer, AeroVironment Nano Hummingbird, Unmanned combat air vehicle, Unmanned ground vehicle, Unmanned space vehicle, Unmanned surface vehicle, Unmanned underwater vehicle, Autonomous underwater vehicle

Transport

Emerging technology	Status	Potentially marginalized technologies	Potential applications	Related articles
Airless tire	Research, development, early prototypes[120][121][122]	Conventional tire[122]	Safer tires[122]	Tweel
Alternative fuel vehicle	Commercialization, diffusion	Internal combustion engine	Reducing air pollution, decreasing oil consumption	Electric vehicle, Hydrogen vehicle
Beam-powered propulsion	Theory			Laser propulsion
Driverless car	Research, development, prototypes[123][124][125]	Driver's licenses, rules of the road, traffic lights, traffic sign, highway patrols, vehicle insurances	Reducing traffic collision, increasing road capacity, reducing air pollution, reducing traffic congestion	Google driverless car, General Motors EN-V, CityCar, MIT Car
Flexible wings (X-53 Active Aeroelastic Wing, Adaptive Compliant Wing), fluidic flight controls	Experiments, prototypes[126][127][128][129][130]	Other flight control systems: ailerons, elevators, elevons, flaps, flaperons	Controlling aircraft, ships	Aircraft flight control system, BAE Systems Demon, fluidics
Flying car	Early commercialization, prototypes[131][132]	Automobile, road	More effective transportation	Terrafugia Transition, Moller M400 Skycar, Urban Aeronautics X-Hawk
Hovertrain, Ground effect train	Research, development[133][134]	Conventional trains	Trains with higher speed	Aérotrain, Duke Hospital PRT, Hovercraft
Ion thruster	In use			
Jet pack or backpack helicopter	Early commercialization, prototypes[135][136]	Automobile	More effective transportation	
Maglev train, Vactrain	Research, early commercialization[137][138][139]	Conventional trains	Trains with higher speed	Shanghai Maglev Train, Linimo

Mass driver	Prototypes			
Personal rapid transit	Early commercialization, diffusion[140][141]	Automobile	More effective transportation	Morgantown PRT, ULTra
Propellant depot	Research, development	Heavy lift rockets	enabling deep-space missions with more massive payloads, satellite life extension, ultimately lowering the cost per kg launched to space	
Pulse detonation engine	Testbed demos			
Reusable launch system	Research, development	Expendable launch system	Surface-to-orbit transport	SpaceX Grasshopper
Scramjet	Research, development[142][143][144]	Conventional jet engine	Hypersonic aircraft	NASA X-43
Solar sail	In 2010, IKAROS was the world's first spacecraft designed to use solar sailing propulsion to be successfully launched		Space travel	
Space elevator	Research, development[145]			Non-rocket spacelaunch, Orbital ring, Sky hook, Space fountain
Spaceplane	Research, development[146][147][148]	Conventional airliners	Hypersonic transport	A2, Skylon
Supersonic transport	Commercialization existed, diffusion	Conventional airliners	Airliner with higher speed	Concorde, Tupolev Tu-144

Other

Emerging technology	Status	Potentially marginalized technologies	Potential applications	Related articles
Anti-gravity	Theory and experiments[149][150]			
Arcology	Theory			
Biometrics	Diffusion	Keys and ID documents		
Bioplastic	Some products developed	Fossil fuel plastics		
Cloak of invisibility	Successful experiments cloaking small objects under some conditions[151][152]	Camouflage[152]	Cloaking microscope tips at optical frequencies[152]	Metamaterial cloaking
Digital scent technology	Diffusion			Smell-O-Vision, iSmell
Domed city	NASA develops a geodesic dome for a moon base		Weather-controlled city, colonization of the moon	

Force field	Theory, experiments[153]	Armor	Military and law enforcement, space travel	Plasma window
Hypertelescope	Theory		astronomy	
Immersive virtual reality	Theory, limited commercialization	Consensus reality	An artificial environment where the user feels just as immersed as they usually feel in consensus reality.	Virtusphere, 3rd Space Vest, haptic suit, immersive technology, simulated reality, holodeck (fictional)
Inflatable space habitat	Developed, prototypes built and tested	Traditional "aluminium can" space habitat modules	Space habitats	Bigelow Aerospace
LED lamp	Commercialization	Incandescent lights, compact fluorescent lights		
Magnetic levitation	Research, development, Commercialization (Maglev Train)	Wheels, tires, conventional transportation systems	High temperature superconductivity, cryogenics, low temperature refrigerators, superconducting magnet design and construction, fiber reinforced plastics for vehicles and structural concretes, communication and high power solid-state controls, vehicle design (aerodynamics and noise mitigation), precision manufacturing, construction and fabrication of concrete structures,[154] maglev car, maglev based spacecraft launch	Levicar
Magnetic refrigeration	Already used for achieving cryogenic temperatures in the laboratory setting (below 10K)	Conventional refrigerators	Refrigeration without the need for compression and with more energy efficient which may be in refrigerators, air conditioners and spacecrafts	
Magnetorheological fluid	developed and researched	Shock absorber	Magnetorheological damper heavy motor damping, operator seat/cab damping in construction vehicles, seismic dampers positioned in building absorbing detrimental shock waves and oscillations within the structure making them earthquake-proof, enhance body armor fluid bullet resistant, Humvees, and various other all-terrain vehicles employ dynamic MR shock absorbers/dampers. Magnetorheological finishing was used in the construction of the Hubble Space Telescope's corrective lens, shock absorbers of a vehicle's suspension are filled with magnetorheological fluid.	Electrorheological fluid
Miniaturized satellite	Research, development, some prototypes	Conventional satellites	Inexpensive satellites, constellations for low data rate communications, using formations to gather data from multiple points, in-orbit inspection of larger satellites.	
Synthetic biology, synthetic genomics	Research, development, first synthetic bacteria created May 2010[155][156]	Chemical industry, petroleum industry, process manufacturing	Creating infinitely scalable production processes based on programmable species of bacteria and other life forms	BioBrick, iGEM, synthetic genomics

Vehicular communication systems	Research and development, some diffusion	Automobile safety	vehicle safety obstacle inform others warnings on entering intersections, Traffic management Accommodating ambulances, fire trucks, and police cars to a specific situation such as hot pursuits and bad weather, Driver assistance systems, Automated highways.	Artificial Passenger, Dedicated short-range communications, Intelligent transportation system
Atmospheric carbon dioxide removal	Research and development	Fossil carbon sources	Climate change mitigation, closing the carbon cycle, input for carbon neutral fuel production	Carbon dioxide removal, Virgin Earth Challenge

Notes

- IEEE International Conference on Emerging Technologies and Factory Automation, & Fuertes, J. M. (1999). 1999 7th IEEE International Conference on Emerging Technologies and Factory Automation proceedings, ETFA'99, October 18–21, 1999, UPC, Barcelona, Catalonia, Spain. Piscataway, N.J.: Institute of Electrical and Electronics Engineers.
- Jones-Garmil, K. (1997). The wired museum: Emerging technology and changing paradigms. Washington, DC: American Association of Museums.
- Giersch, H. (1982). Emerging technologies: Consequences for economic growth, structural change, and employment : symposium 1981. Tübingen: Mohr.

References

[1] International Congress Innovation and Technology XXI: Strategies and Policies Towards the XXI Century, & Soares, O. D. D. (1997). Innovation and technology: Strategies and policies. Dordrecht: Kluwer Academic.

[2] "Is in vitro meat the future?" (http://www.timesonline.co.uk/tol/life_and_style/health/features/article3894871.ece). The Times. 8 May 2008. . Retrieved 16 April 2011.

[3] "Coming soon, the test-tube burger: Lab-grown meat 'needed to feed the world'" (http://www.dailymail.co.uk/sciencetech/article-2008347/Test-tube-burger-coming-soon-Lab-grown-meat-needed-feed-world.html). Daily Mail. 27 June 2011. . Retrieved 18 November 2011.

[4] "Artificial meat: Hamburger junction" (http://www.economist.com/node/21548147). The Economist. 25 February 2012. . Retrieved 3 March 2012.

[5] "Vertical farming - Does it really stack up?" (http://www.economist.com/node/17647627). The Economist. 9 December 2010. . Retrieved 18 November 2011.

[6] "Vertical Farming - Can Urban Agriculture Feed a Hungry World?" (http://www.spiegel.de/international/zeitgeist/0,1518,775754,00.html). Spiegel. 22 July 2011. . Retrieved 18 November 2011.

[7] "A giant leap into the unknown: GM salmon that grows and grows" (http://www.independent.co.uk/news/science/a-giant-leap-into-the-unknown-gm-salmon-that-grows-and-grows-2085856.html). The Independent. 22 September 2010. . Retrieved 5 May 2011.

[8] "Gene therapy is cure for 'boy in the bubble' syndrome" (http://www.telegraph.co.uk/health/8720207/Gene-therapy-is-cure-for-boy-in-the-bubble-syndrome.html). The Telegraph. 24 August 2011. . Retrieved 18 November 2011.

[9] "Frankenstein fears after head transplant" (http://news.bbc.co.uk/1/hi/health/1263758.stm). BBC News. 6 April 2001. . Retrieved 27 December 2011.

[10] "TV programme reveals the REAL Frankensteins" (http://www.dailymail.co.uk/sciencetech/article-426765/TV-programme-reveals-REAL-Frankensteins.html). Daily Mail. 5 January 2007. . Retrieved 27 December 2011.

[11] "Surgeon to do first head transplants" (http://www.iol.co.za/scitech/technology/surgeon-to-do-first-head-transplants-1.10702). Independent Online. 28 August 1999. . Retrieved 27 December 2011.

[12] "Patients to be frozen into state of suspended animation for surgery" (http://www.telegraph.co.uk/health/healthnews/8024991/Patients-to-be-frozen-into-state-of-suspended-animation-for-surgery.html). The Telegraph. 26 September 2010. . Retrieved 21 April 2011.

[13] "Doubt on Anti-Aging Molecule as Drug Trial Stops" (http://www.nytimes.com/2011/01/11/science/11aging.html). The New York Times. 10 January 2011. . Retrieved 1 May 2011.

[14] "Signs of ageing halted in the lab" (http://www.bbc.co.uk/news/health-15552964). BBC News. 2 November 2011. . Retrieved 16 December 2011.

[15] "Stem cells could hold key to 'stopping ageing' say scientists after trial triples mouse lifespan" (http://www.dailymail.co.uk/sciencetech/article-2081734/Stem-cells-hold-key-stopping-ageing-say-scientists-successful-mouse-trial.html). Daily Mail. 4 January 2012. . Retrieved 3

March 2012.
[16] "Aiming for clinical excellence" (http://www.guardian.co.uk/nanotechnology-world/aiming-for-clinical-excellence?newsfeed=true). The Guardian. 26 November 2011. . Retrieved 16 December 2011.
[17] "Nanotechnoglogy world: Nanomedicine offers new cures" (http://www.guardian.co.uk/nanotechnology-world/science-nano-technology-cancer-cure-disease-medicine). The Guardian. 6 September 2011. . Retrieved 16 December 2011.
[18] "Genetic test could be used to 'personalise' drugs, say scientists" (http://www.independent.co.uk/news/science/genetic-test-could-be-used-to-personalise-drugs-say-scientists-1913662.html). The Independent. 1 March 2010. . Retrieved 16 April 2011.
[19] "Scientists Grow Viable Urethras From Boys' Cells" (http://www.foxnews.com/health/2011/03/08/scientists-grow-viable-urethras-boys-cells/). Fox News. 8 March 2011. . Retrieved 27 April 2011.
[20] "Doctors grapple with the value of robotic surgery" (http://www.chron.com/news/article/Doctors-grapple-with-the-value-of-robotic-surgery-2174855.php). Houston Chronicle. 16 September 2011. . Retrieved 24 December 2011.
[21] "Robotic surgery making inroads in many medical procedures" (http://www.thejakartapost.com/news/2011/08/03/robotic-surgery-making-inroads-many-medical-procedures.html). The Jakarta Post. 8 March 2011. . Retrieved 24 December 2011.
[22] "Doctors Perform First Fully Robotic Surgery" (http://www.pcworld.com/article/208490/doctors_perform_first_fully_robotic_surgery.html). PC World. 21 October 2010. . Retrieved 24 December 2011.
[23] "Scientists make eye's retina from stem cells" (http://www.bbc.co.uk/news/health-12963297). BBC News. 6 April 2011. . Retrieved 27 April 2011.
[24] "Medical marvels" (http://www.guardian.co.uk/science/2009/jan/30/stemcells-genetics). The Guardian. 30 January 2009. . Retrieved 16 December 2011.
[25] "Artificial blood vessels created on a 3D printer" (http://www.bbc.co.uk/news/technology-14946808). BBC News. 16 September 2011. . Retrieved 26 December 2011.
[26] "Penis tissue replaced in the lab" (http://news.bbc.co.uk/1/hi/health/8347008.stm). BBC News. 10 November 2009. . Retrieved 26 December 2011.
[27] "U.S. scientists create artificial lungs, of sorts" (http://uk.reuters.com/article/2010/06/24/health-us-lung-artificial-idUKTRE65N5AF20100624). Reuters. 24 June 2010. . Retrieved 26 December 2011.
[28] "Silkworms could aid a breakthrough in tissue engineering" (http://www.bbc.co.uk/news/world-radio-and-tv-16194574). BBC News. 15 December 2011. . Retrieved 26 December 2011.
[29] "Research updates: CMU prof wins grants for very cool technology" (http://www.post-gazette.com/pg/10223/1079017-115.stm). Pittsburgh Post-Gazette. 11 August 2010. . Retrieved 18 November 2011.
[30] "3D display technology is no headache, claim researchers" (http://www.theengineer.co.uk/sectors/electronics/news/3d-display-technology-is-no-headache-claim-researchers/1008140.article). The Engineer. 5 April 2011. . Retrieved 17 April 2011.
[31] "'Glasses-free 3D' hits big time as Toshiba sets a date and price for 55-inch set - with a resolution FOUR TIMES hi-def" (http://www.dailymail.co.uk/sciencetech/article-2071603/Glasses-free-3D-hits-big-time-Toshiba-sets-date-price-55-inch-set--resolution-FOUR-TIMES-hi-def.html). Daily Mail. 8 December 2011. . Retrieved 22 December 2011.
[32] "LG set to sell 55-inch TV using new OLED technology" (http://www.taipeitimes.com/News/biz/archives/2012/01/03/2003522255). Taipei Times. 2 January 2012. . Retrieved 3 January 2011.
[33] "The TV of the future arrives early: Incredible pictures of 55-inch flatscreen just 4mm thick" (http://www.dailymail.co.uk/sciencetech/article-2081183/Incredible-pictures-55-inch-flatscreen-thats-just-4mm-thick.html). Daily Mail. 2 January 2012. . Retrieved 3 January 2011.
[34] "Natural iridescence harnessed for reflective displays" (http://www.eetimes.com/electronics-news/4084036/Natural-iridescence-harnessed-for-reflective-displays). EE Times. 26 July 2009. . Retrieved 5 May 2011.
[35] "Google 'to unveil' hi-tech Google Glasses that put a screen of information over the world" (http://www.dailymail.co.uk/sciencetech/article-2076742/Google-unveil-hi-tech-Google-glasses-superimpose-information-world.html). Daily Mail. 20 December 2011. . Retrieved 22 December 2011.
[36] McManamon P.F. et al. (May 15, 1996). "Optical phased array technology" (http://cat.inist.fr/?aModele=afficheN&cpsidt=3024704). *Proceedings of the IEEE, Laser radar applications* (IEEE) **84** (2): 99–320. . Retrieved 29 April 2011.
[37] Wowk B (1996). "Phased Array Optics" (http://www.phased-array.com/1996-Book-Chapter.html). In BC Crandall. *Molecular Speculations on Global Abundance*. MIT Press. pp. 147–160. ISBN 0-262-03237-6. . Retrieved 29 April 2011.
[38] "Scientist: Holographic television to become reality" (http://edition.cnn.com/2008/TECH/science/10/06/holographic.television/). CNN. 7 October 2008. . Retrieved 29 April 2011.
[39] "Holographic video takes step forward with updated display" (http://www.independent.co.uk/life-style/gadgets-and-tech/holographic-video-takes-step-forward-with-updated-display-2125847.html). The Independent. 5 November 2010. . Retrieved 29 April 2011.
[40] "Phone calls in 3-D soon" (http://www.nst.com.my/articles/323d/Article). New Straits Times. 9 January 2011. . Retrieved 29 April 2011.
[41] "Tuberculosis breakthrough as scientists get funds for 'electronic nose'" (http://www.guardian.co.uk/global-development/2011/nov/07/tuberculosis-electronic-nose-device). The Guardian. 7 November 2011. . Retrieved 4 December 2011.
[42] "Now, a mobile phone that can smell" (http://timesofindia.indiatimes.com/tech/personal-tech/computing/Now-a-mobile-phone-that-can-smell/articleshow/10642819.cms). The Times of India. 7 November 2011. . Retrieved 4 December 2011.

[43] "Electronic Cotton" (http://spectrum.ieee.org/semiconductors/materials/electronic-cotton). IEEE Spectrum. January 2012. . Retrieved 4 March 2012.
[44] "Flexible future: Forget the iPhone, here's the smartphone made out of 'paper' that will shape with your pocket" (http://www.dailymail.co.uk/sciencetech/article-1383903/PaperPhone-The-smartphone-paper-shape-pocket.html). Daily Mail. 6 May 2011. . Retrieved 18 November 2011.
[45] "Technology... or magic? Samsung shows off video of transparent, flexible screen - with 3D so real it looks like you can touch it" (http://www.dailymail.co.uk/sciencetech/article-2070741/Samsungs-transparent-flexible-screen-3D-real-looks-like-touch-it.html). Daily Mail. 7 December 2011. . Retrieved 7 December 2011.
[46] "Remapping Computer Circuitry to Avert Impending Bottlenecks" (http://www.nytimes.com/2011/03/01/science/01compute.html). The New York Times. 28 February 2011. . Retrieved 27 April 2011.
[47] "Memristor revolution backed by HP" (http://www.bbc.co.uk/news/technology-11165087). BBC News. 2 September 2010. . Retrieved 27 April 2011.
[48] "Scientists developing spintronic computer chips" (http://articles.timesofindia.indiatimes.com/2011-04-14/computing/29417322_1_electrons-devices-spintronic). The Times of India. 14 April 2011. . Retrieved 17 April 2011.
[49] "Getting wind farms off the ground" (http://www.economist.com/node/9249242). The Economist. 7 June 2007. . Retrieved 7 December 2011.
[50] "Wind turbines take to the skies" (http://www.bbc.co.uk/news/10217289). BBC News. 3 June 2010. . Retrieved 7 December 2011.
[51] "Airborne Wind Turbines" (http://www.nytimes.com/2007/12/09/magazine/09_1_turbine.html). The New York Times. 9 December 2007. . Retrieved 7 December 2011.
[52] "Solar 'Artificial Leaf' Is Unveiled by Researchers" (http://www.reuters.com/article/2011/03/29/idUS81168260920110329). Reuters. 29 March 2011. . Retrieved 21 April 2011.
[53] "Lufthansa to start trials with biofuel from Neste" (http://in.reuters.com/article/2010/11/29/lufthansa-biofuels-idINLDE6AS1IU20101129). Reuters. 29 November 2010. . Retrieved 4 May 2011.
[54] "California approves Tessera solar plant" (http://www.reuters.com/article/2010/10/28/us-solar-calico-idUKTRE69R5YQ20101028). Reuters. 28 October 2010. . Retrieved 4 May 2011.
[55] "Ultracapacitors Gain Traction as Battery Alternative" (http://www.reuters.com/article/2011/03/30/idUS305904663820110330). Reuters. 30 March 2011. . Retrieved 4 May 2011.
[56] "In China the big nuclear question is "how soon"?" (http://www.reuters.com/article/2011/05/03/china-nuclear-idUSL3E7FR0HZ20110503). Reuters. 3 May 2011. . Retrieved 4 May 2011.
[57] "MIT develops way to bank solar energy at home" (http://uk.reuters.com/article/2008/07/31/us-energy-solar-fuelcells-idUKN3145191020080731). Reuters. 31 July 2008. . Retrieved 24 December 2011.
[58] "All eyes on Bloom Box fuel cell launch" (http://www.guardian.co.uk/environment/2010/feb/22/bloom-box-fuel-cell-launch). The Guardian. 22 February 2010. . Retrieved 24 December 2011.
[59] "Japan aims its home fuel cells at Europe" (http://news.bbc.co.uk/1/hi/8563928.stm). BBC News. 12 March 2010. . Retrieved 24 December 2011.
[60] "Hydrogen tries again" (http://www.economist.com/node/15981031). The Economist. 23 April 2010. . Retrieved 4 May 2011.
[61] Kraytsberg A, Ein-Eli Y (2011). "Review on Li-air batteries - Opportunities, limitations and perspective". Journal of Power Sources,196:p.886-893.
[62] "Scientists say paper battery could be in the works" (http://uk.reuters.com/article/2009/12/07/battery-paper-idUKN075599520091207). Reuters. 7 December 2009. . Retrieved 4 May 2011.
[63] "Microfiber fabric makes its own electricity?" (http://in.reuters.com/article/2008/02/13/us-shirt-idINN1334900820080213). Reuters. 14 February 2008. . Retrieved 4 May 2011.
[64] "A new device to tap more solar energy invented" (http://www.thehindu.com/sci-tech/technology/article2029102.ece). The Hindu. 18 May 2011. . Retrieved 24 December 2011.
[65] "Heat scavenging - Stealing the heat" (http://www.economist.com/node/15582193). The Economist. 4 March 2010. . Retrieved 24 December 2011.
[66] "New Rays" (http://www.businessworld.in/businessworld/content/New-Rays.html?print=yes). Businessworld. 21 May 2011. . Retrieved 24 December 2011.
[67] "Electricity to power 'smart grid'" (http://news.bbc.co.uk/1/hi/technology/8056083.stm). BBC News. 18 May 2009. . Retrieved 4 March 2012.
[68] "Smart Grid Costs Are Massive, but Benefits Will Be Larger, Industry Study Says" (http://www.nytimes.com/cwire/2011/05/25/25climatewire-smart-grid-costs-are-massive-but-benefits-wi-48403.html?pagewanted=all). The New York Times. 25 May 2011. . Retrieved 4 March 2012.
[69] "Pushing the low carbon boundaries: South Korea's smart grid initiative" (http://www.guardian.co.uk/sustainable-business/south-korea-smart-grid-low-carbon). The Guardian. 5 September 2011. . Retrieved 4 March 2012.
[70] "Solar panel roads 'could solve energy crisis'" (http://www.telegraph.co.uk/earth/energy/solarpower/6155110/Solar-panel-roads-could-solve-energy-crisis.html). The Telegraph. 8 September 2009. . Retrieved 9 December 2011.
[71] "Solar-Powered Glass Road Could Melt Snow Automatically" (http://www.foxnews.com/leisure/2011/02/02/solar-powered-glass-road-melt-snow-automatically/). Fox News. 2 February 2011. . Retrieved 9 December 2011.

[72] "Road network could become solar power grid" (http://www.wired.co.uk/news/archive/2010-09/24/solar-roadways). Wired. 24 September 2010. . Retrieved 9 December 2011.

[73] "Wireless energy promise powers up" (http://news.bbc.co.uk/1/hi/6725955.stm). BBC News. 7 June 2007. . Retrieved 4 May 2011.

[74] IBM *Next Five in Five 2010* (a prediction of five emerging technologies expected in by 2015). See IBM's new 'Next Five in Five' list peers into the future (http://www.thetechherald.com/article.php/201051/6605/IBM-s-new-Next-Five-in-Five-list-peers-into-the-future), TechHerald Dec 24 2010.

[75] "The big plan to build a brain" (http://www.telegraph.co.uk/science/roger-highfield/8587577/The-big-plan-to-build-a-brain.html). The Telegraph. 21 June 2011. . Retrieved 18 November 2011.

[76] "IBM's Watson supercomputer crowned Jeopardy king" (http://www.bbc.co.uk/news/technology-12491688). BBC News. 17 February 2011. . Retrieved 17 April 2011.

[77] "MIT scientists take a step closer to artificial intelligence" (http://www.computerweekly.com/news/2240111287/MIT-scientists-take-a-step-closer-to-artificial-intelligence). Computer Weekly. 18 November 2011. . Retrieved 18 November 2011.

[78] "How innovative is Apple's new voice assistant, Siri?" (http://www.newscientist.com/article/mg21228365.300-how-innovative-is-apples-new-voice-assistant-siri.html). New Scientist. 3 November 2011. . Retrieved 4 March 2012.

[79] "G.E.'s breakthrough can put 100 DVDs on a disc" (http://www.tehrantimes.com/index_View.asp?code=193312). Tehran Times. 28 April 2009. . Retrieved 29 April 2011.

[80] "eyeSight CEO Gideon Shmuel: The Company Making Minority Report A Reality (Finally)" (http://www.huffingtonpost.co.uk/2012/07/30/eyesight-ceo-gideon-shmue_n_1719637.html). The Huffington Post. 30 July 2012. . Retrieved 31 July 2012.

[81] "Get Sampark, go multilingual" (http://www.thehindu.com/sci-tech/internet/article1594491.ece). The Hindu. 3 April 2011. . Retrieved 29 April 2011.

[82] "The big plan to build a brain" (http://www.telegraph.co.uk/science/roger-highfield/8587577/The-big-plan-to-build-a-brain.html). The Telegraph. 21 June 2011. . Retrieved 18 November 2011.

[83] "Mobile Video Collaboration System Securely Connects Field Staff and Experts" (http://www.ecnmag.com/Products/2011/03/Computer-Peripherals/Mobile-Video-Collaboration-System/). *Electronic Component News*. March 28, 2011. .

[84] "New hand-held device targets work on shop floor: veteran high-tech team launches new venture" (http://www.librestream.com?News/July_11_2005.html). *Winnipeg Free Press*. July 11, 2005. .

[85] "US scientists build first 'antilaser'" (http://www.abc.net.au/science/articles/2011/02/18/3142398.htm). ABC. 18 February 2011. . Retrieved 21 April 2011.

[86] "Quantum computing device hints at powerful future" (http://www.bbc.co.uk/news/science-environment-12811199). BBC News. 22 March 2011. . Retrieved 17 April 2011.

[87] "First Ever Commercial Quantum Computer Now Available for $10 Million" (http://www.extremetech.com/article2/0,2845,2385665,00.asp). ExtremeTech. 20 May 2011. . Retrieved 22 May 2011.

[88] "Does quantum mechanics offer the best way to protect our most valuable data?" (http://www.independent.co.uk/news/science/does-quantum-mechanics-offer-the-best-way-to-protect-our-most-valuable-data-2257679.html). The Independent. 31 March 2011. . Retrieved 17 April 2011.

[89] "Will NFC make the mobile wallet work?" (http://www.bbc.co.uk/news/business-15201807). BBC News. 7 October 2011. . Retrieved 8 December 2011.

[90] "Internet of things: Should you worry if your jeans go smart?" (http://www.bbc.co.uk/news/business-15004063). BBC News. 23 September 2011. . Retrieved 8 December 2011.

[91] "RFID tagging: Chips with everything" (http://www.telegraph.co.uk/technology/5355741/RFID-tagging-Chips-with-everything.html). The Telegraph. 20 May 2009. . Retrieved 8 December 2011.

[92] "Intel goes 3D with transistor redesign" (http://www.guardian.co.uk/technology/2011/may/04/intel-3d-chip-tri-gate). The Guardian. 4 May 2011. . Retrieved 19 November 2011.

[93] "Intel unveils 22nm 3D Ivy Bridge processor" (http://www.bbc.co.uk/news/technology-13283882). BBC News. 4 May 2011. . Retrieved 19 November 2011.

[94] "3D Printing May Bring Legal Challenges, Group Says" (http://www.pcworld.com/businesscenter/article/210346/3d_printing_may_bring_legal_challenges_group_says.html). PC World. 10 November 2010. . Retrieved 16 April 2011.

[95] "3D printing: the technology that could re-shape the world" (http://www.telegraph.co.uk/technology/news/8666516/3D-printing-the-technology-that-could-re-shape-the-world.html). The Telegraph. 28 July 2011. . Retrieved 18 November 2011.

[96] "Sto AG, Cabot Create Aerogel Insulation" (http://www.constructiondigital.com/innovations/sto-ag-cabot-create-aerogel-insulation). Construction Digital. 15 November 2011. . Retrieved 18 November 2011.

[97] "Is graphene a miracle material?" (http://news.bbc.co.uk/1/hi/programmes/click_online/9491789.stm). BBC Click. 21 May 2011. . Retrieved 18 November 2011.

[98] "Could graphene be the new silicon?" (http://www.guardian.co.uk/science/2011/nov/13/graphene-research-novoselov-geim-manchester). The Guardian. 13 November 2011. . Retrieved 18 November 2011.

[99] "Applications of Graphene under Development" (http://www.understandingnano.com/graphene-applications.html). understandingnano.com. .

[100] "The 'new age' of super materials" (http://news.bbc.co.uk/1/hi/6412057.stm). BBC News. 5 March 2007. . Retrieved 27 April 2011.

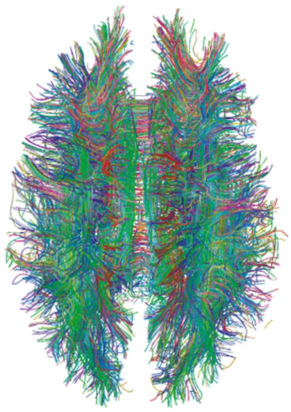
[101] "Strides in Materials, but No Invisibility Cloak" (http://www.nytimes.com/2010/11/09/science/09meta.html?_r=1). The New York Times. 8 November 2010. . Retrieved 21 April 2011.
[102] NAE Website: Frontiers of Engineering (http://www.nae.edu/?ID=8683). Nae.edu. Retrieved on 2011-02-22.
[103] "Carbon nanotubes used to make batteries from fabrics" (http://news.bbc.co.uk/1/hi/8471362.stm). BBC News. 21 January 2010. . Retrieved 27 April 2011.
[104] "Researchers One Step Closer to Building Synthetic Brain" (http://www.dailytech.com/Researchers+One+Step+Closer+to+Building+Synthetic+Brain/article21459c.htm). Daily Tech. 25 April 2011. . Retrieved 27 April 2011.
[105] "Pentagon Developing Shape-Shifting 'Transformers' for Battlefield" (http://www.foxnews.com/story/0,2933,525565,00.html). Fox News. 10 June 2009. . Retrieved 26 April 2011.
[106] "Intel: Programmable matter takes shape" (http://www.zdnetasia.com/intel-programmable-matter-takes-shape-62045198.htm). ZD Net. 22 August 2008. . Retrieved 2 January 2012.
[107] "'Quantum dots' to boost performance of mobile cameras" (http://news.bbc.co.uk/1/hi/technology/8580372.stm). BBC News. 22 March 2010. . Retrieved 16 April 2011.
[108] "Laser gun tested on US Navy ship in Pacific Ocean" (http://www.bbc.co.uk/news/technology-13034521). BBC News. 11 April 2011. . Retrieved 18 April 2011.
[109] "Electromagnetic weapons - Frying tonight" (http://www.economist.com/node/21532245). The Economist. 15 October 2011. . Retrieved 19 November 2011.
[110] "Navy Sets World Record With Incredible, Sci-Fi Weapon" (http://www.foxnews.com/scitech/2010/12/10/navy-railgun-shoots-bullets-electromagnet/). Fox News. 10 December 2010. . Retrieved 19 November 2011.
[111] "Mind-reading research: the major breakthroughs" (http://www.telegraph.co.uk/science/science-news/8782214/Mind-reading-research-the-major-breakthroughs.html). The Telegraph. 22 September 2011. . Retrieved 18 November 2011.
[112] "'Mind-reading device' recreates what we see in our heads" (http://www.telegraph.co.uk/science/science-news/8781503/Mind-reading-device-recreates-what-we-see-in-our-heads.html#disqus_thread). The Telegraph. 22 September 2011. . Retrieved 18 November 2011.
[113] "It was only a matter of time: Study shows how scientists can now 'read your mind'" (http://www.dailymail.co.uk/news/article-2078614/Study-shows-scientists-read-mind.html). Daily Mail. 26 December 2011. . Retrieved 27 December 2011.
[114] "Mind-reading device could become reality" (http://www.telegraph.co.uk/science/science-news/9051909/Mind-reading-device-could-become-reality.html). The Telegraph. 31 January 2012. . Retrieved 4 March 2012.
[115] "IBM predicts it will be making 'mind-controlled' PCs within five years" (http://www.dailymail.co.uk/sciencetech/article-2077019/IBM-predicts-making-mind-controlled-PCs-years.html). Daily Mail. 21 December 2011. . Retrieved 21 December 2011.
[116] "'Mind Control' Possible in 5 Years: IBM" (http://www.nbcbayarea.com/news/local/IBM-Mind-Control-Possible-in-5-Years-IBM-135884763.html). NBC Bay Area. 21 December 2011. . Retrieved 21 December 2011.
[117] "Tiny motors may be big in surgery" (http://news.bbc.co.uk/1/hi/7837967.stm). BBC News. 20 January 2009. . Retrieved 21 April 2011.
[118] Christopher Mims (2009). "Exoskeletons Give New Life to Legs" (http://www.sciam.com/article.cfm?id=honda-exoskeleton-assist-devices). Scientific American. . Retrieved 2009-04-21.
[119] "Riders on a swarm" (http://www.economist.com/node/16789226). The Economist. 12 August 2010. . Retrieved 21 April 2011.
[120] "Airless Tire Promises Grace Under Pressure for Soldiers" (http://www.scientificamerican.com/article.cfm?id=tires-that-dont-need-air). Scientific American. 11 August 2008. . Retrieved 6 December 2011.
[121] "New tire models to go without air or oil" (http://www.yomiuri.co.jp/dy/business/T111205005170.htm). The Daily Yomiuri. 6 December 2011. . Retrieved 6 December 2011.
[122] "Well, blow me: Airless tyre that never goes flat could put an end to punctures" (http://www.dailymail.co.uk/sciencetech/article-2090275/Well-blow-Airless-tyre-goes-flat-end-punctures.html). Daily Mail. 22 January 2012. . Retrieved 3 March 2012.
[123] "BMW's new driverless car still a decade away" (http://smh.drive.com.au/motor-news/bmws-new-driverless-car-still-a-decade-away-20111123-1nuci.html). Sydney Morning Herald. 23 November 2011. . Retrieved 4 December 2011.
[124] "Driverless car navigates streets" (http://www.belfasttelegraph.co.uk/breaking-news/offbeat/driverless-car-navigates-streets-16052550.html). Belfast Telegraph. 20 September 2011. . Retrieved 4 December 2011.
[125] "Robotic car developed by Oxford University" (http://www.bbc.co.uk/news/uk-england-oxfordshire-15214477). BBC News. 10 October 2011. . Retrieved 4 December 2011.
[126] Scott, William B. (27 November 2006), "Morphing Wings" (http://www.aviationweek.com/aw/), *Aviation Week & Space Technology*,
[127] "FlexSys Inc.: Aerospace" (http://www.flxsys.com/aerospace.shtml). . Retrieved 26 April 2011.
[128] Kota, Sridhar; Osborn, Russell; Ervin, Gregory; Maric, Dragan; Flick, Peter; Paul, Donald. "Mission Adaptive Compliant Wing – Design, Fabrication and Flight Test" (http://www.flxsys.com/pdf/NATO_Conf_Paper-KOTA.pdf). Ann Arbor, MI; Dayton, OH, U.S.A.: FlexSys Inc., Air Force Research Laboratory. . Retrieved 26 April 2011.
[129] "Showcase UAV Demonstrates Flapless Flight" (http://www.baesystems.com/AboutUs/ShowcaseUAVDemonstratesFlaplessFlight/). BAE Systems. 2010. . Retrieved 2010-12-22.
[130] "Demon UAV jets into history by flying without flaps" (http://www.metro.co.uk/news/842292-plane-jets-into-history-by-flying-without-flaps). *Metro.co.uk* (London: Associated Newspapers Limited). 28 September 2010. .

Retrieved 29 September 2010.
[131] "Terrafugia Transition flying car to go into proudction after US approval" (http://www.theaustralian.com.au/news/lifestyle/terrafugia-transition-flying-car-to-go-into-proudction-after-us-approval/story-e6frg9zo-1225886520998). The Australian. 1 July 2010. . Retrieved 6 December 2011.
[132] "Stuck in traffic? Turn your car into a plane in 30 secs" (http://articles.timesofindia.indiatimes.com/2010-07-02/science/28319061_1_roadable-aircraft-car-traffic-jam). The Times of India. 2 July 2010. . Retrieved 6 December 2011.
[133] "Flying train unveiled by Japanese scientists" (http://www.cnngo.com/explorations/life/japanese-scientists-invent-trains-flies-976740). CNN. 13 May 2011. . Retrieved 7 December 2011.
[134] "Robot plane-train uses ground-effect principle to levitate" (http://www.wired.co.uk/news/archive/2011-05/12/ground-effect-train). Wired. 12 May 2011. . Retrieved 7 December 2011.
[135] "Going up in the world? Beat the rush hour with first commercial jetpack for £50,000" (http://www.dailymail.co.uk/sciencetech/article-1253670/First-commercial-jetpack-sale-50-000.html). Daily Mail. 26 February 2010. . Retrieved 6 December 2011.
[136] "Flying into the future: New Zealand company to make personal jet packs" (http://www.telegraph.co.uk/news/worldnews/australiaandthepacific/newzealand/7307195/Flying-into-the-future-New-Zealand-company-to-make-personal-jet-packs.html). The Telegraph. 24 February 2010. . Retrieved 6 December 2011.
[137] "China scientists claim 1,200 kph train" (http://www.cnngo.com/shanghai/life/china-maglev-train-hits-1200-kph-636051). CNN. 1 February 2011. . Retrieved 7 December 2011.
[138] "Laboratory working on train to run at 1,000 kph" (http://www.shanghaidaily.com/sp/article/2010/201008/20100803/article_445162.htm). Shanghai Daily. 3 August 2010. . Retrieved 7 December 2011.
[139] "How vactrains work" (http://seattletimes.nwsource.com/html/living/2012635431_webstuff17.html). The Seattle Times. 16 August 2010. . Retrieved 7 December 2011.
[140] "Pod Cars Start to Gain Traction in Some Cities" (http://wheels.blogs.nytimes.com/2010/09/20/pod-cars-start-to-gain-traction-in-some-cities/?partner=rss&emc=rss). The New York Times. 20 September 2010. . Retrieved 7 December 2011.
[141] "Are driverless pods the future?" (http://news.bbc.co.uk/1/hi/uk/7148731.stm). BBC News. 18 December 2007. . Retrieved 7 December 2011.
[142] "China Developing Scramjet Propulsion" (http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=defense&id=news/aw090307p2.xml). Aviation Week. 2 September 2007. . Retrieved 6 December 2011.
[143] "X-51A Scramjet Fails On Second Attempt" (http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=defense&id=news/awx/2011/06/15/awx_06_15_2011_p0-336299.xml&headline=X-51A Scramjet Fails On Second Attempt). Aviation Week. 15 June 2011. . Retrieved 6 December 2011.
[144] "On hybrid, space travel will not cost the earth" (http://articles.timesofindia.indiatimes.com/2010-03-23/science/28144801_1_scramjet-mach-air-breathing). The Times of India. 23 March 2010. . Retrieved 6 December 2011.
[145] "Robot passes test in space elevator contest" (http://www.washingtonpost.com/wp-dyn/content/article/2009/11/04/AR2009110405052.html). The Washington Post. 5 November 2009. . Retrieved 19 November 2011.
[146] "Plans to develop space-plane are go" (http://www.theaustralian.com.au/news/world/plans-to-develop-space-plane-are-go/story-e6frg6so-1111117793952). The Australian. 20 October 2008. . Retrieved 7 December 2011.
[147] "UK Skylon spaceplane passes key review" (http://www.bbc.co.uk/news/science-environment-13506289). BBC News. 24 May 2011. . Retrieved 7 December 2011.
[148] "Air Force says it's extending mission of mysterious X-37B" (http://latimesblogs.latimes.com/money_co/2011/11/x37b-space-plane-air-force.html). Los Angeles Times. 29 November 2011. . Retrieved 7 December 2011.
[149] "BAe's anti-gravity research braves X-Files ridicule" (http://www.guardian.co.uk/science/2000/mar/27/uknews). The Guardian. 27 March 2000. . Retrieved 4 December 2011.
[150] "Boeing joins race to defeat gravity" (http://www.telegraph.co.uk/news/worldnews/northamerica/usa/1403060/Boeing-joins-race-to-defeat-gravity.html). The Telegraph. 30 July 2002. . Retrieved 4 December 2011.
[151] Rachel Kaufman (28 January 2011). "New Invisibility Cloak Closer to Working "Magic"" (http://news.nationalgeographic.com/news/2011/01/110128-invisibility-cloak-magic-crystal-mit-barbastathis-science/). *National Geographic News*. . Retrieved February 4, 2011.
[152] "Breakthrough in bid to create 'invisibility cloak' as 3D object is made to vanish for first time" (http://www.dailymail.co.uk/sciencetech/article-2091792/Invisibility-cloak-breakthrough-3D-object-vanish-time.html). Daily Mail. 26 January 2012. . Retrieved 3 March 2012.
[153] "Star Trek-style force-field armour being developed by military scientists" (http://www.telegraph.co.uk/technology/news/7487740/Star-Trek-style-force-field-armour-being-developed-by-military-scientists.html). The Telegraph. 20 March 2010. . Retrieved 16 April 2011.
[154] "The Potential for Maglev Applications" (http://inventors.about.com/library/inventors/blrailroad5.htm). about.com. .
[155] "'Artificial life' breakthrough announced by scientists" (http://www.bbc.co.uk/news/10132762). BBC News. 20 May 2010. . Retrieved 29 April 2011.
[156] "Scientist Craig Venter creates life for first time in laboratory sparking debate about 'playing god'" (http://www.telegraph.co.uk/science/7745868/Scientist-Craig-Venter-creates-life-for-first-time-in-laboratory-sparking-debate-about-playing-god.html). The Telegraph. 20 May 2010. . Retrieved 29 April 2011.

External links

- Special Reports 10 Emerging Technologies (http://www.technologyreview.com/special/emerging/). Technology Review.
- ET.gov site (http://et.gov/)
- UpcomingTechnology.ORG (http://www.upcomingtechnology.org/new-technology/upcoming/)
- Techcast.org- A Technology Forecast site (http://www.techcast.org/forecasts.aspx)

Connectome


White matter tracts within a human brain, as visualized by MRI tractography.

A **connectome** is a comprehensive map of neural connections in the brain.

The production and study of connectomes, known as connectomics, may range in scale from a detailed map of the full set of neurons and synapses within part or all of the nervous system of an organism to a macro scale description of the functional and structural connectivity between all cortical areas and subcortical structures. The term "connectome" is used primarily in scientific efforts to capture, map, and understand the organization of neural interactions within the brain. One such effort is the Human Connectome Project, sponsored by the National Institutes of Health, whose focus is to build a network map of the human brain in healthy, living adults. Another was the successful reconstruction of all neural and synaptic connections in *C. elegans* (White et al., 1986,[1] Varshney et al., 2011[2]). Partial connectomes of a mouse retina [3] and mouse primary visual cortex [4] have also been successfully reconstructed. Bock et al.'s complete 12TB data set is publicly available at Open Connectome Project [5].

Origin and usage of the term "connectome"

In 2005, Dr. Olaf Sporns at Indiana University and Dr. Patric Hagmann at Lausanne University Hospital independently and simultaneously suggested the term "connectome" to refer to a map of the neural connections within the brain. This term was directly inspired by the ongoing effort to sequence the human genetic code—to build a genome.

"Connectomics" (Hagmann, 2005) has been defined as the science concerned with assembling and analyzing connectome data sets.[6]

In their 2005 paper, *The Human Connectome, a structural description of the human brain*, Sporns *et al.* wrote:

> To understand the functioning of a network, one must know its elements and their interconnections. The purpose of this article is to discuss research strategies aimed at a comprehensive structural description of the network of elements and connections forming the human brain. We propose to call this dataset the human "connectome," and we argue that it is fundamentally important in cognitive neuroscience and neuropsychology. The connectome will significantly increase our understanding of how functional brain states emerge from their underlying structural substrate, and will provide new mechanistic insights into how brain function is affected if this structural substrate is disrupted.[7]

In his 2005 Ph.D. thesis, *From diffusion MRI to brain connectomics*, Hagmann wrote:

> It is clear that, like the genome, which is much more than just a juxtaposition of genes, the set of all neuronal connections in the brain is much more than the sum of their individual components. The genome is an entity

> it-self, as it is from the subtle gene interaction that [life] emerges. In a similar manner, one could consider the brain connectome, set of all neuronal connections, as one single entity, thus emphasizing the fact that the huge brain neuronal communication capacity and computational power critically relies on this subtle and incredibly complex connectivity architecture.[6]

Pathways through cerebral white matter can be charted by histological dissection and staining, by degeneration methods, and by axonal tracing. Axonal tracing methods form the primary basis for the systematic charting of long-distance pathways into extensive, species-specific anatomical connection matrices between gray matter regions. Landmark studies have included the areas and connections of the visual cortex of the macaque (Felleman and Van Essen, 1991)[8] and the thalamo-cortical system in the feline brain (Scannell et al., 1999).[9] The development of neuroinformatics databases for anatomical connectivity allow for continual updating and refinement of such anatomical connection maps. The online macaque cortex connectivity tool CoCoMac (Kötter, 2004)[10] is a prominent example of such a database.

In the human brain, the significance of the connectome stems from the realization that the structure and function of the human brain are intricately linked, through multiple levels and modes of brain connectivity. There are strong natural constraints on which neurons or neural populations can interact, or how strong or direct their interactions are. Indeed, the foundation of human cognition lies in the pattern of dynamic interactions shaped by the connectome.

However, structure-function relationships in the brain are unlikely to reduce to simple one-to-one mappings. In fact, the connectome can evidently support a great number of variable dynamic states, depending on current sensory inputs, global brain state, learning and development. Some changes in functional state may involve rapid changes of structural connectivity at the synaptic level, as has been elucidated by two-photon imaging experiments showing the rapid appearance and disappearance of dendritic spines (Bonhoeffer and Yuste, 2002).[11]

Despite such complex and variable structure-function mappings, the connectome is an indispensable basis for the mechanistic interpretation of dynamic brain data, from single-cell recordings to functional neuroimaging.

The term "connectome" was more recently popularized by Sebastian Seung's "I am my Connectome" speech given at the 2010 TED conference, which discusses the high-level goals of mapping the human connectome, as well as ongoing efforts to build a three-dimensional neural map of brain tissue at the microscale.[12]

The connectome at multiple scales

Brain networks can be defined at different levels of scale, corresponding to levels of spatial resolution in brain imaging (Kötter, 2007, Sporns, 2010).[13][14] These scales can be roughly categorized as microscale, mesoscale and macroscale. Ultimately, it may be possible to join connectomic maps obtained at different scales into a single hierarchical map of the neural organization of a given species that ranges from single neurons to populations of neurons to larger systems like cortical areas. Given the methodological uncertainties involved in inferring connectivity from the primary experimental data, and given that there are likely to be large differences in the connectomes of different individuals, any unified map will likely rely on *probabilistic* representations of connectivity data (Sporns et al., 2005).[7]

Mapping the connectome at the "microscale" (micrometer resolution) means building a complete map of the neural systems, neuron-by-neuron. The challenge of doing this becomes obvious: the number of neurons comprising the brain easily ranges into the billions in more highly evolved organisms. According to various estimates, the human cerebral cortex alone contains at least 10^{10} neurons linked by 10^{14} synaptic connections. By comparison, the number of base-pairs in a human genome is 3×10^9. A few of the main challenges of building a human connectome at the microscale today include: (1) data collection would take years given current technology, (2) machine vision tools to annotate the data remain in their infancy, and are inadequate, and (3) neither theory nor algorithms are readily available for the analysis of the resulting *brain-graphs.* To address the data collection issues, several groups are building high-throughput serial electron microscopes (Kasthuri et al., 2009; Bock et al. 2011). To address the machine-vision and image-processing issues, the Open Connectome Project [5] is *alg-sourcing* (algorithm

outsourcing) this hurdle. Finally, statistical graph theory is an emerging discipline which is developing sophisticated pattern recognition and inference tools to parse these brain-graphs (Goldenberg et al., 2009).

A "mesoscale" connectome corresponds to a spatial resolution of hundreds of micrometers. Rather than attempt to map each individual neuron, a connectome at the mesoscale would attempt to capture anatomically and/or functionally distinct neuronal populations, formed by local circuits (e.g. cortical columns) that link hundreds or thousands of individual neurons. This scale still presents a very ambitious technical challenge at this time and can only be probed on a small scale with invasive techniques or very high field MRI on a local scale.

A connectome at the macroscale (millimeter resolution) attempts to capture large brain systems that can be parcellated into anatomically distinct modules (areas, parcels or nodes), each having a distinct pattern of connectivity. Connectomic databases at the mesoscale and macroscale may be significantly more compact than those at cellular resolution, but they require effective strategies for accurate anatomical or functional parcellation of the neural volume into network nodes (for complexities see, e.g., Wallace et al., 2004).[15]

Mapping the connectome at the cellular level

Current non-invasive imaging techniques cannot capture the brain's activity on a neuron-by-neuron level. Mapping the connectome at the cellular level in vertebrates currently requires post-mortem microscopic analysis of limited portions of brain tissue.

Traditional histological circuit-mapping approaches have included light-microscopic techniques for cell staining, injection of labeling agents for tract tracing, or reconstruction of serially sectioned tissue blocks via electron microscopy (EM). Each of these classical approaches has specific drawbacks when it comes to deployment for connectomics. The staining of single cells, e.g. with the Golgi stain, to trace cellular processes and connectivity suffers from the limited resolution of light-microscopy as well as difficulties in capturing long-range projections. Tract tracing, often described as the "gold standard" of neuroanatomy for detecting long-range pathways across the brain, generally only allows the tracing of fairly large cell populations and single axonal pathways. EM reconstruction was successfully used for the compilation of the C. elegans connectome (White et al., 1986).[1] However, applications to larger tissue blocks of entire nervous systems have traditionally had difficulty with projections that span longer distances.

Recent advances in mapping neural connectivity at the cellular level offer significant new hope for overcoming the limitations of classical techniques and for compiling cellular connectome data sets (Livet et al., 2007; Lichtman et al., 2008).[16][17][18] Using a combinatorial color labeling method based on the stochastic expression of several fluorescent proteins, called Brainbow, Lichtman and colleagues were able to mark individual neurons with one of over 100 distinct colors. The labeling of individual neurons with a distinguishable hue then allows the tracing and reconstruction of their cellular structure including long processes within a block of tissue.

In March 2011, the journal Nature published a pair of articles on micro-connectomes: Bock et al.[4] and Briggman et al.[3] In both articles, the authors first characterized the functional properties of a small subset of cells, and then manually traced a subset of the processes emanating from those cells to obtain a partial subgraph. In alignment with the principles of open-science, the authors of Bock et al. (2011) have released their data for public access. The full resolution 12TB dataset from Bock et al. is available at the Open Connectome Project [5].

Mapping the connectome at the macro scale

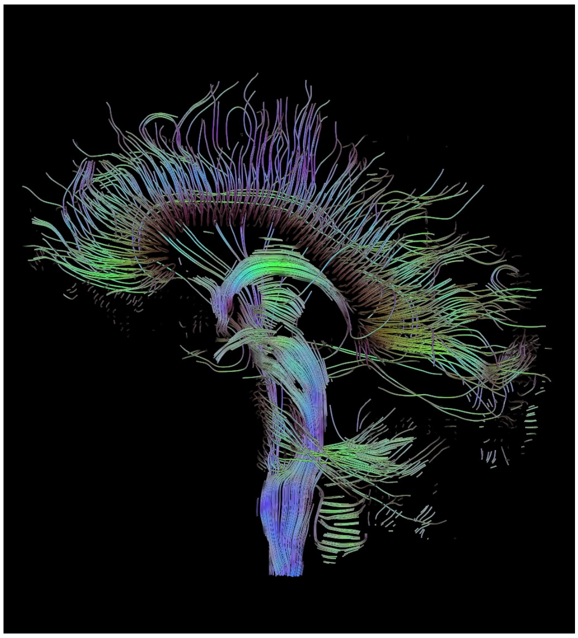
Established methods of brain research, such as axonal tracing, provided early avenues for building connectome data sets. However, more recent advances in living subjects has been made by the use of non-invasive imaging technologies such as diffusion magnetic resonance imaging and functional magnetic resonance imaging (fMRI). The first, when combined with tractography allows reconstruction of the major fiber bundles in the brain. The second allows the researcher to capture the brain's network activity (either at rest or while performing directed tasks),

enabling the identification of structurally and anatomically distinct areas of the brain that are functionally connected.

Notably, the goal of the Human Connectome Project, led by the WU-Minn consortium, is to build a *structural and functional map* of the healthy human brain at the macro scale, using a combination of multiple imaging technologies and resolutions.

Recent advances in connectivity mapping

Over the past few years, several investigators have attempted to map the large-scale structural architecture of the human cortex. One attempt exploited cross-correlations in cortical thickness or volume across individuals (He et al., 2007).[19] Such gray-matter thickness correlations have been postulated as indicators for the presence of structural connections. A drawback of the approach is that it provides highly indirect information about cortical connection patterns and requires data from large numbers of individuals to derive a single connection data set across a subject group.


Tractographic reconstruction of neural connections via DTI

Other investigators have attempted to build whole-brain connection matrices from diffusion imaging data. One group of researchers (Iturria-Medina et al., 2008)[20] has constructed connectome data sets using diffusion tensor imaging (DTI) followed by the derivation of average connection probabilities between 70-90 cortical and basal brain gray matter areas. All networks were found to have small-world attributes and "broad-scale" degree distributions. An analysis of betweenness centrality in these networks demonstrated high centrality for the precuneus, the insula, the superior parietal and the superior frontal cortex. Another group (Gong et al. 2008)[21] has applied DTI to map a network of anatomical connections between 78 cortical regions. This study also identified several hub regions in the human brain, including the precuneus and the superior frontal gyrus.

Hagmann et al. (2007)[22] constructed a connection matrix from fiber densities measured between homogeneously distributed and equal-sized regions of interest (ROIs) numbering between 500 and 4000. A quantitative analysis of connection matrices obtained for approximately 1000 ROIs and approximately 50,000 fiber pathways from two subjects demonstrated an exponential (one-scale) degree distribution as well as robust small-world attributes for the network. The data sets were derived from diffusion spectrum imaging (DSI) (Wedeen, 2005),[23] a variant of diffusion-weighted imaging that is sensitive to intra-voxel heterogeneities in diffusion directions caused by crossing fiber tracts and thus allows more accurate mapping of axonal trajectories than other diffusion imaging approaches (Wedeen, 2008).[24] The combination of whole-head DSI datasets acquired and processed according to the approach developed by Hagmann et al. (2007)[22] with the graph analysis tools conceived initially for animal tracing studies (Sporns, 2006; Sporns, 2007)[25][26] allow a detailed study of the network structure of human cortical connectivity (Hagmann et al., 2008).[27] The human brain network was characterized using a broad array of network analysis methods including core decomposition, modularity analysis, hub classification and centrality. Hagmann et al. presented evidence for the existence of a structural core of highly and mutually interconnected brain regions, located primarily in posterior medial and parietal cortex. The core comprises portions of the posterior cingulate cortex, the precuneus, the cuneus, the paracentral lobule, the isthmus of the cingulate, the banks of the superior temporal sulcus, and the inferior and superior parietal cortex, all located in both cerebral hemispheres.

Primary challenge for macroscale connectomics: determining parcellations of the brain

The initial explorations in macroscale human connectomics were done using either equally sized regions or anatomical regions with unclear relationship to the underlying functional organization of the brain (e.g. gyral and sulcal-based regions). While much can be learned from these approaches, it is highly desirable to parcellate the brain into functionally distinct parcels: brain regions with distinct architectonics, connectivity, function, and/or topography (Felleman and Van Essen, 1991).[8] Accurate parcellation allows each node in the macroscale connectome to be more informative by associating it with a distinct connectivity pattern and functional profile. Parcellation of localized areas of cortex have been accomplished using diffusion tractography (Beckmann *et al.* 2009)[28] and functional connectivity (Nelson *et al.* 2010)[29] to non-invasively measure connectivity patterns and define cortical areas based on distinct connectivity patterns. Such analyses may best be done on a whole brain scale and by integrating non-invasive modalities. Accurate whole brain parcellation may lead to more accurate macroscale connectomes for the normal brain, which can then be compared to disease states.

Mapping functional connectivity to complement anatomical connectivity

Using functional MRI (fMRI) in the resting state and during tasks, functions of the connectome circuits are being studied.[30] Just as detailed road maps of the earth's surface do not tell us much about the kind of vehicles that travel those roads or what cargo they are hauling, to understand how neural structures result in specific functional behavior such as consciousness, it is necessary to build theories that relate functions to anatomical connectivity.[31]

References

[1] White, J. G.; Southgate, E.; Thomson, J. N.; Brenner, S. (1986). "The Structure of the Nervous System of the Nematode Caenorhabditis elegans". *Philosophical Transactions of the Royal Society B: Biological Sciences* **314** (1165): 1–340. Bibcode 1986RSPTB.314....1W. doi:10.1098/rstb.1986.0056.

[2] Varshney, L. R.; Chen, B. L.; Paniagua, E.; Hall, D. H.; Chklovskii, D. B. (2011). Sporns, Olaf. ed. "Structural Properties of the Caenorhabditis elegans Neuronal Network". *PLoS Computational Biology* **7** (2): e1001066. Bibcode 2011PLSCB...7E0010V. doi:10.1371/journal.pcbi.1001066. PMC 3033362. PMID 21304930.

[3] Briggman KL, Helmstaedter M, Denk W. (2011 Mar 10). "Wiring specificity in the direction-selectivity circuit of the retina.". *Nature* **471** (7337): 183–8. Bibcode 2011Natur.471..183B. doi:10.1038/nature09818.

[4] Davi D. Bock, Wei-Chung Allen Lee, Aaron M. Kerlin, Mark L. Andermann, Greg Hood, Arthur W. Wetzel, Sergey Yurgenson, Edward R. Soucy, Hyon Suk Kim & R. Clay Reid. "Network anatomy and in vivo physiology of visual cortical neurons" (http://www.nature.com/nature/journal/v471/n7337/full/nature09802.html). *Nature* **471** (7337): 177–182. Bibcode 2011Natur.471..177B. doi:10.1038/nature09802. PMID 21390124. .

[5] http://openconnectomeproject.org

[6] "master.dvi" (http://library.epfl.ch/en/theses/?nr=3230) (PDF). . Retrieved 2011-08-07.

[7] Sporns, Olaf; Tononi, Giulio; Kötter, Rolf (2005). "The Human Connectome: A Structural Description of the Human Brain". *PLoS Computational Biology* **1** (4): e42. Bibcode 2005PLSCB...1...42S. doi:10.1371/journal.pcbi.0010042. PMC 1239902. PMID 16201007.

[8] Felleman, Daniel J.; Van Essen, David C. (1991). "Distributed Hierarchical Processing in the Primate Cerebral Cortex". *Cerebral Cortex* **1** (1): 1–47. doi:10.1093/cercor/1.1.1-a. PMID 1822724.

[9] Scannell, J.W.; Burns, GA; Hilgetag, CC; O'Neil, MA; Young, MP (1999). "The Connectional Organization of the Cortico-thalamic System of the Cat". *Cerebral Cortex* **9** (3): 277–99. doi:10.1093/cercor/9.3.277. PMID 10355908.

[10] Kötter, Rolf (2004). "Online Retrieval, Processing, and Visualization of Primate Connectivity Data From the CoCoMac Database". *Neuroinformatics* **2** (2): 127–44. doi:10.1385/NI:2:2:127. PMID 15319511.

[11] Bonhoeffer, Tobias; Yuste, Rafael (2002). "Spine MotilityPhenomenology, Mechanisms, and Function". *Neuron* **35** (6): 1019–27. doi:10.1016/S0896-6273(02)00906-6. PMID 12354393.

[12] "Sebastian Seung: I am my connectome | Video on" (http://www.ted.com/talks/sebastian_seung.html). Ted.com. . Retrieved 2011-08-07.

[13] Kötter, Rolf (2007). "Anatomical Concepts of Brain Connectivity". *Handbook of Brain Connectivity*. Understanding Complex Systems. pp. 149–67. doi:10.1007/978-3-540-71512-2_5. ISBN 978-3-540-71462-0.

[14] "Networks of the Brain - The MIT Press" (http://mitpress.mit.edu/catalog/item/default.asp?ttype=2&tid=12288). Mitpress.mit.edu. 2010-11-30. . Retrieved 2011-08-07.

[15] Wallace, M. T. (2004). "A revised view of sensory cortical parcellation". *Proceedings of the National Academy of Sciences* **101** (7): 2167–72. Bibcode 2004PNAS..101.2167W. doi:10.1073/pnas.0305697101.

[16] Livet, Jean; Weissman, Tamily A.; Kang, Hyuno; Draft, Ryan W.; Lu, Ju; Bennis, Robyn A.; Sanes, Joshua R.; Lichtman, Jeff W. (2007). "Transgenic strategies for combinatorial expression of fluorescent proteins in the nervous system". *Nature* **450** (7166): 56–62. Bibcode 2007Natur.450...56L. doi:10.1038/nature06293. PMID 17972876.

[17] Lichtman, J; Sanes, J (2008). "Ome sweet ome: what can the genome tell us about the connectome?". *Current Opinion in Neurobiology* **18** (3): 346–53. doi:10.1016/j.conb.2008.08.010. PMC 2735215. PMID 18801435.

[18] Lichtman, Jeff W.; Livet, Jean; Sanes, Joshua R. (2008). "A technicolour approach to the connectome". *Nature Reviews Neuroscience* **9** (6): 417–22. doi:10.1038/nrn2391. PMC 2577038. PMID 18446160.

[19] He, Y.; Chen, Z. J.; Evans, A. C. (2006). "Small-World Anatomical Networks in the Human Brain Revealed by Cortical Thickness from MRI". *Cerebral Cortex* **17** (10): 2407–19. doi:10.1093/cercor/bhl149. PMID 17204824.

[20] Iturria-Medina, Yasser; Sotero, Roberto C.; Canales-Rodríguez, Erick J.; Alemán-Gómez, Yasser; Melie-García, Lester (2008). "Studying the human brain anatomical network via diffusion-weighted MRI and Graph Theory". *NeuroImage* **40** (3): 1064–76. doi:10.1016/j.neuroimage.2007.10.060. PMID 18272400.

[21] Gong, G.; He, Y.; Concha, L.; Lebel, C.; Gross, D. W.; Evans, A. C.; Beaulieu, C. (2008). "Mapping Anatomical Connectivity Patterns of Human Cerebral Cortex Using In Vivo Diffusion Tensor Imaging Tractography". *Cerebral Cortex* **19** (3): 524–36. doi:10.1093/cercor/bhn102. PMC 2722790. PMID 18567609.

[22] Hagmann, Patric; Thiran, Jean-Philippe; Meuli, Reto (2007). Sporns, Olaf. ed. "Mapping Human Whole-Brain Structural Networks with Diffusion MRI". *PLoS ONE* **2** (7): e597. Bibcode 2007PLoSO...2..597H. doi:10.1371/journal.pone.0000597. PMC 1895920. PMID 17611629.

[23] Wedeen, Van J.; Hagmann, Patric; Tseng, Wen-Yih Isaac; Reese, Timothy G.; Weisskoff, Robert M. (2005). "Mapping complex tissue architecture with diffusion spectrum magnetic resonance imaging". *Magnetic Resonance in Medicine* **54** (6): 1377–86. doi:10.1002/mrm.20642. PMID 16247738.

[24] Wedeen, V.J.; Wang, R.P.; Schmahmann, J.D.; Benner, T.; Tseng, W.Y.I.; Dai, G.; Pandya, D.N.; Hagmann, P. et al. (2008). "Diffusion spectrum magnetic resonance imaging (DSI) tractography of crossing fibers". *NeuroImage* **41** (4): 1267–77. doi:10.1016/j.neuroimage.2008.03.036. PMID 18495497.

[25] Sporns, O (2006). "Small-world connectivity, motif composition, and complexity of fractal neuronal connections". *Bio Systems* **85** (1): 55–64. doi:10.1016/j.biosystems.2006.02.008. PMID 16757100.

[26] Kaiser, Marcus; Sporns, Olaf; Honey, Christopher J.; Kötter, Rolf (2007). Kaiser, Marcus. ed. "Identification and Classification of Hubs in Brain Networks". *PLoS ONE* **2** (10): e1049. Bibcode 2007PLoSO...2.1049S. doi:10.1371/journal.pone.0001049. PMC 2013941. PMID 17940613.

[27] Hagmann, Patric; Cammoun, Leila; Gigandet, Xavier; Meuli, Reto; Honey, Christopher J.; Wedeen, Van J.; Sporns, Olaf (2008). Friston, Karl J.. ed. "Mapping the Structural Core of Human Cerebral Cortex". *PLoS Biology* **6** (7): e159. doi:10.1371/journal.pbio.0060159. PMC 2443193. PMID 18597554.

[28] Beckmann, M.; Johansen-Berg, H.; Rushworth, M. F. S. (2009). "Connectivity-Based Parcellation of Human Cingulate Cortex and Its Relation to Functional Specialization". *Journal of Neuroscience* **29** (4): 1175–90. doi:10.1523/JNEUROSCI.3328-08.2009. PMID 19176826.

[29] Nelson, Steven M.; Cohen, Alexander L.; Power, Jonathan D.; Wig, Gagan S.; Miezin, Francis M.; Wheeler, Mark E.; Velanova, Katerina; Donaldson, David I. et al. (2010). "A Parcellation Scheme for Human Left Lateral Parietal Cortex". *Neuron* **67** (1): 156–70. doi:10.1016/j.neuron.2010.05.025. PMC 2913443. PMID 20624599.

[30] Functional Connectivity (http://jn.physiology.org/content/103/1/297.short) "Intrinsic Functional Connectivity As a Tool For Human Connectomics"

[31] Consciousness and Connectomics (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3110420/) "Consciousness, Plasticity, and Connectomics: The Role of Intersubjectivity in Human Cognition", Micah Allen and Gary Williams *Frontiers in Psychology*, (February 28, 2011); vol 2: num 20, doi:10.3389/fpsyg.2011.00020

External links

- Open Connectome Project (http://openconnectomeproject.org/)
- The Connectome Project at Harvard (http://iic.seas.harvard.edu/research/the-connectome/)
- The official site for the NIH-sponsored Human Connectome Project (http://humanconnectome.org/consortia/)
- The NITRC Human Connectome Project Site (http://www.nitrc.org/projects/hcp/)
- Connectome Research by EPFL/CHUV, Lausanne, Switzerland (http://www.connectomics.org/)
- The NIH Blueprint for Neuroscience Research (http://neuroscienceblueprint.nih.gov/)
- Connectome Research led by Dr. Shawn Mikula (http://www.connectomes.org)
- http://www.youtube.com/watch?v=HA7GwKXfJB0 TED talk by Sebastian Seung: I am my connectome.

Computational neuroscience

Computational neuroscience is the study of brain function in terms of the information processing properties of the structures that make up the nervous system.[1] It is an interdisciplinary science that links the diverse fields of neuroscience, cognitive science and psychology with electrical engineering, computer science, mathematics and physics.

Computational neuroscience is distinct from psychological connectionism and theories of learning from disciplines such as machine learning, neural networks and computational learning theory in that it emphasizes descriptions of functional and biologically realistic neurons (and neural systems) and their physiology and dynamics. These models capture the essential features of the biological system at multiple spatial-temporal scales, from membrane currents, protein and chemical coupling to network oscillations, columnar and topographic architecture and learning and memory. These computational models are used to frame hypotheses that can be directly tested by current or future biological and/or psychological experiments.

History

The term "computational neuroscience" was introduced by Eric L. Schwartz, who organized a conference, held in 1985 in Carmel, California at the request of the Systems Development Foundation, to provide a summary of the current status of a field which until that point was referred to by a variety of names, such as neural modeling, brain theory and neural networks. The proceedings of this definitional meeting were later published as the book "Computational Neuroscience" (1990).[2]

The early historical roots of the field can be traced to the work of people such as Louis Lapicque, Hodgkin & Huxley, Hubel & Wiesel, and David Marr, to name but a few. Lapicque introduced the integrate and fire model of the neuron in a seminal article published in 1907;[3] this model is still one of the most popular models in computational neuroscience for both cellular and neural networks studies, as well as in mathematical neuroscience because of its simplicity (see the recent review article[4] published recently for the centenary of the original Lapicque's 1907 paper - this review also contains an English translation of the original paper). About 40 years later, Hodgkin & Huxley developed the voltage clamp and created the first biophysical model of the action potential. Hubel & Wiesel discovered that neurons in the primary visual cortex, the first cortical area to process information coming from the retina, have oriented receptive fields and are organized in columns.[5] David Marr's work focused on the interactions between neurons, suggesting computational approaches to the study of how functional groups of neurons within the hippocampus and neocortex interact, store, process, and transmit information. Computational modeling of biophysically realistic neurons and dendrites began with the work of Wilfrid Rall, with the first multicompartmental model using cable theory.

Major topics

Research in computational neuroscience can be roughly categorized into several lines of inquiry. Most computational neuroscientists collaborate closely with experimentalists in analyzing novel data and synthesizing new models of biological phenomena.

Single-neuron modeling

Even single neurons have complex biophysical characteristics. Hodgkin and Huxley's original model only employed two voltage-sensitive currents, the fast-acting sodium and the inward-rectifying potassium. Though successful in predicting the timing and qualitative features of the action potential, it nevertheless failed to predict a number of important features such as adaptation and shunting. Scientists now believe that there are a wide variety of voltage-sensitive currents, and the implications of the differing dynamics, modulations and sensitivity of these

currents is an important topic of computational neuroscience.[6]

The computational functions of complex dendrites are also under intense investigation. There is a large body of literature regarding how different currents interact with geometric properties of neurons.[7]

Some models are also tracking biochemical pathways at very small scales such as spines or synaptic clefts.

There are many software packages, such as GENESIS and NEURON, that allow rapid and systematic *in silico* modeling of realistic neurons. Blue Brain, a project founded by Henry Markram from the École Polytechnique Fédérale de Lausanne, aims to construct a biophysically detailed simulation of a cortical column on the Blue Gene supercomputer.

Development, axonal patterning and guidance

How do axons and dendrites form during development? How do axons know where to target and how to reach these targets? How do neurons migrate to the proper position in the central and peripheral systems? How do synapses form? We know from molecular biology that distinct parts of the nervous system release distinct chemical cues, from growth factors to hormones that modulate and influence the growth and development of functional connections between neurons.

Theoretical investigations into the formation and patterning of synaptic connection and morphology are still nascent. One hypothesis that has recently garnered some attention is the *minimal wiring hypothesis*, which postulates that the formation of axons and dendrites effectively minimizes resource allocation while maintaining maximal information storage.[8]

Sensory processing

Early models of sensory processing understood within a theoretical framework is credited to Horace Barlow. Somewhat similar to the minimal wiring hypothesis described in the preceding section, Barlow understood the processing of the early sensory systems to be a form of efficient coding, where the neurons encoded information which minimized the number of spikes. Experimental and computational work have since supported this hypothesis in one form or another.

Current research in sensory processing is divided among biophysical modelling of different subsystems and more theoretical modelling of perception. Current models of perception have suggested that the brain performs some form of Bayesian inference and integration of different sensory information in generating our perception of the physical world.

Memory and synaptic plasticity

Earlier models of memory are primarily based on the postulates of Hebbian learning. Biologically relevant models such as Hopfield net have been developed to address the properties of associative, rather than content-addressable style of memory that occur in biological systems. These attempts are primarily focusing on the formation of medium-term and long-term memory, localizing in the hippocampus. Models of working memory, relying on theories of network oscillations and persistent activity, have been built to capture some features of the prefrontal cortex in context-related memory.[9]

One of the major problems in neurophysiological memory is how it is maintained and changed through multiple time scales. Unstable synapses are easy to train but also prone to stochastic disruption. Stable synapses forget less easily, but they are also harder to consolidate. One recent computational hypothesis involves cascades of plasticity[10] that allow synapses to function at multiple time scales. Stereochemically detailed models of the acetylcholine receptor-based synapse with Monte Carlo method, working at the time scale of microseconds, have been built.[11] It is likely that computational tools will contribute greatly to our understanding of how synapses function and change in relation to external stimulus in the coming decades.

Behaviors of networks

Biological neurons are connected to each other in a complex, recurrent fashion. These connections are, unlike most artificial neural networks, sparse and most likely, specific. It is not known how information is transmitted through such sparsely connected networks. It is also unknown what the computational functions, if any, of these specific connectivity patterns are.

The interactions of neurons in a small network can be often reduced to simple models such as the Ising model. The statistical mechanics of such simple systems are well-characterized theoretically. There has been some recent evidence that suggests that dynamics of arbitrary neuronal networks can be reduced to pairwise interactions.(Schneidman et al., 2006; Shlens et al., 2006.)[12] It's unknown, however, whether such descriptive dynamics impart any important computational function. With the emergence of two-photon microscopy and calcium imaging, we now have powerful experimental methods with which to test the new theories regarding neuronal networks.

In some cases the complex interactions between *inhibitory* and *excitatory* neurons can be simplified using mean field theory that gives rise to population model of neural networks. While many neuro-theorists prefer such models with reduced complexity, others argue that uncovering structure function relations depends on including as much neuronal and network structure as possible. Models of this type are typically built in large simulations platforms like GENESIS or Neuron. There have been some attempts to provide unified methods that bridge and integrate these levels of complexity.[13]

Cognition, discrimination and learning

Computational modeling of higher cognitive functions has only recently begun. Experimental data comes primarily from single-unit recording in primates. The frontal lobe and parietal lobe function as integrators of information from multiple sensory modalities. There are some tentative ideas regarding how simple mutually inhibitory functional circuits in these areas may carry out biologically relevant computation.[14]

The brain seems to be able to discriminate and adapt particularly well in certain contexts. For instance, human beings seem to have an enormous capacity for memorizing and recognizing faces. One of the key goals of computational neuroscience is to dissect how biological systems carry out these complex computations efficiently and potentially replicate these processes in building intelligent machines.

The brain's large-scale organizational principles are illuminated by many fields, including biology, psychology, and clinical practice. Integrative neuroscience attempts to consolidate these observations through unified descriptive models and databases of behavioral measures and recordings. These are the basis for some quantitative modeling of large-scale brain activity.[15]

The Computational Representational Understanding of Mind (CRUM) is another attempt at modeling human cognition through simulated processes like acquired rule-based systems in decision making and the manipulation of visual representations in decision making.

Consciousness

One of the ultimate goals of psychology/neuroscience is to be able to explain the everyday experience of conscious life. Francis Crick and Christof Koch made some attempts in formulating a consistent framework for future work in neural correlates of consciousness (NCC), though much of the work in this field remains speculative.[16]

References

Notes

[1] What is computational neuroscience? Patricia S. Churchland, Christof Koch, Terrence J. Sejnowski. in Computational Neuroscience pp.46-55. Edited by Eric L. Schwartz. 1993. MIT Press (http://mitpress.mit.edu/catalog/item/default.asp?ttype=2&tid=7195)

[2] Schwartz, Eric (1990). *Computational neuroscience*. Cambridge, Mass: MIT Press. ISBN 0-262-19291-8.

[3] Lapicque L (1907). "Recherches quantitatives sur l'excitation électrique des nerfs traitée comme une polarisation". *J. Physiol. Pathol. Gen.* **9**: 620–635.

[4] Brunel N, Van Rossum MC (2007). "Lapicque's 1907 paper: from frogs to integrate-and-fire". *Biol. Cybern.* **97** (5–6): 337–339. doi:10.1007/s00422-007-0190-0. PMID 17968583.

[5] Hubel DH, Wiesel TN (1962). "Receptive fields, binocular interaction and functional architecture in the cat's visual cortex" (http://www.jphysiol.org/cgi/pmidlookup?view=long&pmid=14449617). *J. Physiol. (Lond.)* **160** (1): 106–54. PMC 1359523. PMID 14449617. .

[6] Wu, Samuel Miao-sin; Johnston, Daniel (1995). *Foundations of cellular neurophysiology*. Cambridge, Mass: MIT Press. ISBN 0-262-10053-3.

[7] Koch, Christof (1999). *Biophysics of computation: information processing in single neurons*. Oxford [Oxfordshire]: Oxford University Press. ISBN 0-19-510491-9.

[8] Chklovskii DB, Mel BW, Svoboda K (October 2004). "Cortical rewiring and information storage". *Nature* **431** (7010): 782–8. Bibcode 2004Natur.431..782C. doi:10.1038/nature03012. PMID 15483599.
Review article

[9] Durstewitz D, Seamans JK, Sejnowski TJ (2000). "Neurocomputational models of working memory". *Nat Neurosci.* **3** (Suppl): 1184–91. doi:10.1038/81460. PMID 11127836.

[10] Fusi S, Drew PJ, Abbott LF (2005). "Cascade models of synaptically stored memories". *Neuron* **45** (4): 599–611. doi:10.1016/j.neuron.2005.02.001. PMID 15721245.

[11] Coggan JS, Bartol TM, Esquenazi E, *et al.* (2005). "Evidence for ectopic neurotransmission at a neuronal synapse". *Science* **309** (5733): 446–51. Bibcode 2005Sci...309..446C. doi:10.1126/science.1108239. PMC 2915764. PMID 16020730.

[12] Schneidman E, Berry MJ, Segev R, Bialek W (2006). "Weak pairwise correlations imply strongly correlated network states in a neural population". *Nature* **440** (7087): 1007–12. arXiv:q-bio/0512013. Bibcode 2006Natur.440.1007S. doi:10.1038/nature04701. PMC 1785327. PMID 16625187.

[13] Anderson, Charles H.; Eliasmith, Chris (2004). *Neural Engineering: Computation, Representation, and Dynamics in Neurobiological Systems (Computational Neuroscience)*. Cambridge, Mass: The MIT Press. ISBN 0-262-55060-1.

[14] Machens CK, Romo R, Brody CD (2005). "Flexible control of mutual inhibition: a neural model of two-interval discrimination". *Science* **307** (5712): 1121–4. Bibcode 2005Sci...307.1121M. doi:10.1126/science.1104171. PMID 15718474.

[15] Robinson PA, Rennie CJ, Rowe DL, O'Connor SC, Gordon E (2005). "Multiscale brain modelling". *Philosophical Transactions of the Royal Society B* **360** (1457): 1043–1050. doi:10.1098/rstb.2005.1638. PMC 1854922. PMID 16087447.

[16] Crick F, Koch C (2003). "A framework for consciousness". *Nat Neurosci.* **6** (2): 119–26. doi:10.1038/nn0203-119. PMID 12555104.

General references

- Chklovskii DB (2004). "Synaptic connectivity and neuronal morphology: two sides of the same coin". *Neuron* **43** (5): 609–17. doi:10.1016/j.neuron.2004.08.012. PMID 15339643.
- Sejnowski, Terrence J.; Churchland, Patricia Smith (1992). *The computational brain*. Cambridge, Mass: MIT Press. ISBN 0-262-03188-4.
- Abbott, L. F.; Dayan, Peter (2001). *Theoretical neuroscience: computational and mathematical modeling of neural systems*. Cambridge, Mass: MIT Press. ISBN 0-262-04199-5.
- Eliasmith, Chris; Anderson, Charles H. (2003). *Neural engineering: Representation, computation, and dynamcs in neurobiological systems*. Cambridge, Mass: MIT Press. ISBN 0-262-05071-4.
- Hodgkin AL, Huxley AF (28 August 1952). "A quantitative description of membrane current and its application to conduction and excitation in nerve" (http://www.jphysiol.org/cgi/pmidlookup?view=long&pmid=12991237). *J Physiol. (Lond.)* **117** (4): 500–44. PMC 1392413. PMID 12991237.

- William Bialek; Rieke, Fred; David Warland; Rob de Ruyter van Steveninck (1999). *Spikes: exploring the neural code*. Cambridge, Mass: MIT. ISBN 0-262-68108-0.
- Schutter, Erik de (2001). *Computational neuroscience: realistic modeling for experimentalists*. Boca Raton: CRC. ISBN 0-8493-2068-2.
- Sejnowski, Terrence J.; Hemmen, J. L. van (2006). *23 problems in systems neuroscience*. Oxford [Oxfordshire]: Oxford University Press. ISBN 0-19-514822-3.
- Michael A. Arbib, Shun-ichi Amari, Prudence H. Arbib (2002). *The Handbook of Brain Theory and Neural Networks*. Cambridge, Massachusetts: The MIT Press. ISBN 0-262-01197-2.

External links

Journals

- Network: Computation in Neural Systems (http://www.informaworld.com/network)
- Biological Cybernetics (http://www.springerlink.com/openurl.asp?genre=journal&issn=0340-1200)
- Journal of Computational Neuroscience (http://www.springer.com/10827)
- Neural Computation (http://www.mitpressjournals.org/loi/neco)
- Neural Networks (http://www.sciencedirect.com/science/journal/08936080)
- Neurocomputing (http://www.elsevier.com/locate/neucom)
- Cognitive Neurodynamics (http://www.springerlink.com/content/1871-4099/)
- Frontiers in Computational Neuroscience (http://frontiersin.org/neuroscience/computationalneuroscience/)
- PLoS Computational Biology (http://www.ploscompbiol.org/home.action)
- Frontiers in Neuroinformatics (http://www.frontiersin.org/Journal/specialty.aspx?s=752&name=neuroinformatics&x=y)

Software

- BRIAN, a Python based simulator
- Emergent, neural simulation software.
- GENESIS, a general neural simulation system.
- ModelDB (http://senselab.med.yale.edu/modeldb), a large open-access database of program codes of published computational neuroscience models.
- Nengo (http://nengo.ca), a Python scriptable, GUI simulator for large-scale neural models
- NEST, a simulation tool for large neuronal systems.
- Neuroconstruct (http://www.neuroconstruct.org), software for developing biologically realistic 3D neural networks.
- NEURON (http://www.neuron.yale.edu/), a neuron simulator also useful to simulate neural networks.
- SNNAP (http://snnap.uth.tmc.edu/), a single neuron and neural network simulator tool.
- ReMoto (http://remoto.leb.usp.br/remoto/index.html), a web-based simulator of the spinal cord and innervated muscles of the human leg.

Conferences

- Computational and Systems Neuroscience (COSYNE) (http://www.cosyne.org)– a computational neuroscience meeting with a systems neuroscience focus.
- Annual Computational Neuroscience Meeting (CNS) (http://www.cnsorg.org)– a yearly computational neuroscience meeting.
- Neural Information Processing Systems (NIPS) (http://www.nips.cc)– a leading annual conference covering other machine learning topics as well.
- Computational Cognitive Neuroscience Conference (CCNC) (http://www.ccnconference.org)– a yearly conference.
- International Conference on Cognitive Neurodynamics (ICCN) (http://www.iccn2007.org/)– a yearly conference.
- UK Mathematical Neurosciences Meeting (http://www.icms.org.uk/workshops/mathneuro)– a new yearly conference, focused on mathematical aspects.
- The NeuroComp Conference (http://www.neurocomp.fr/index.php?page=welcome)– a yearly computational neuroscience conference (France).
- Bernstein Conference on Computational Neuroscience (BCCN) (http://www.nncn.de/Aktuelles-en/bernsteinsymposium/Symposium/view?set_language=en)– a yearly conference in Germany, organized by the Bernstein Network for Computational Neuroscience (http://www.nncn.de/willkommen-en/view?set_language=en).
- AREADNE Conferences (http://www.areadne.org/index.html)– a biennial meeting that includes theoretical and experimental results, held in even years in Santorini, Greece.

Websites

- Perlewitz's computational neuroscience on the web (http://home.earthlink.net/~perlewitz/)
- Encyclopedia of Computational Neuroscience (http://www.scholarpedia.org/article/Encyclopedia_of_Computational_Neuroscience), part of Scholarpedia, an online expert curated encyclopedia on computational neuroscience, dynamical systems and machine intelligence

Artificial brain

Artificial brain is a term commonly used in the media[1] to describe research that aims to develop software and hardware with cognitive abilities similar to those of the animal or human brain. Research investigating "artificial brains" plays three important roles in science:

1. An ongoing attempt by neuroscientists to understand how the human brain works, known as cognitive neuroscience.
2. A thought experiment in the philosophy of artificial intelligence, demonstrating that it is possible, in theory, to create a machine that has all the capabilities of a human being.
3. A serious long term project to create machines capable of general intelligent action or Artificial General Intelligence. This idea has been popularised by Ray Kurzweil[2] as strong AI (taken to mean a machine as intelligent as a human being).

An example of the first objective is the project reported by Aston University in Birmingham, England[3] where researchers are using biological cells to create "neurospheres" (small clusters of neurons) in order to develop new treatments for diseases including Alzheimer's, Motor Neurone and Parkinson's Disease.

The second objective is a reply to arguments such as John Searle's Chinese room argument, Hubert Dreyfus' critique of AI or Roger Penrose's argument in *The Emperor's New Mind*. These critics argued that there are aspects of human consciousness or expertise that can not be simulated by machines. One reply to their arguments is that the biological processes inside the brain can be simulated to any degree of accuracy. This reply was made as early as 1950, by Alan Turing in his classic paper "Computing Machinery and Intelligence".[4]

The third objective is generally called artificial general intelligence by researchers.[5] However Kurzweil prefers the more memorable term Strong AI. In his book *The Singularity is Near* he focuses on whole brain emulation using conventional computing machines as an approach to implementing artificial brains, and claims (on grounds of computer power continuing an exponential growth trend) that this could be done by 2025. Henry Markram, director of the Blue Brain project (which is attempting brain emulation), made a similar claim (2020) at the Oxford TED conference in 2009.[1]

Approaches to brain simulation

Although direct brain emulation using artificial neural networks on a high-performance computing engine is a common approach,[6] there are other approaches. An alternative artificial brain implementation could be based on Holographic Neural Technology (HNeT) [2] non linear phase coherence/decoherence principles. The analogy has been made to quantum processes through the core synaptic algorithm which has strong similarities to the QM wave equation.

EvBrain[7] is a form of evolutionary software that can evolve "brainlike" neural networks, such as the network immediately behind the retina.

Since November 2008, IBM received a $4.9 million grant from the Pentagon for research into creating intelligent computers. The Blue Brain project is being conducted with the assistance of IBM in Lausanne.[8] The project is based on the premise that it is possible to artificially link the neurons "in the computer" by placing thirty million synapses in their proper three-dimensional position.

In March 2008, *Blue Brain* project was progressing faster than expected: "Consciousness is just a massive amount of information being exchanged by trillions of brain cells.[9]" Some proponents of strong AI speculate that computers in connection with Blue Brain and Soul Catcher may exceed human intellectual capacity by around 2015, and that it is likely that we will be able to download the human brain at some time around 2050.[10]

There are good reasons to believe that, regardless of implementation strategy, the predictions of realising artificial brains in the near future are optimistic. In particular brains (including the human brain) and cognition are not

currently well understood, and the scale of computation required is unknown. In addition there seem to be power constraints. The brain consumes about 20W of power whereas supercomputers may use as much as 1MW or an order of 100,000 more (note: Landauer limit is 3.5×10^{20} op/sec/watt at room temperature).

Artificial brain thought experiment

Some critics of brain simulation [11] believe that it is simpler to create general intelligent action directly without imitating nature. Some commentators[12] have used the analogy that early attempts to construct flying machines modeled them after birds, but that modern aircraft do not look like birds. A computational argument is used in AI - What is this [13], where it is shown that, if we have a formal definition of general AI, the corresponding program can be found by enumerating all possible programs and then testing each of them to see whether it matches the definition. No appropriate definition currently exists.

In addition, there are ethical issues that should be resolved. The construction and sustenance of an artificial brain raises moral questions, namely regarding personhood, freedom, and death. Does a "brain in a box" constitute a person? What rights would such an entity have, under law or otherwise? Once activated, would human beings have the obligation to continue its operation? Would the shutdown of an artificial brain constitute death, sleep, unconsciousness, or some other state for which no human description exists? After all, an artificial brain is not subject to post-mortem cellular decay (and associated loss of function) as human brains are, so an artificial brain could, theoretically, resume functionality exactly as it was before it was shut down.

References

[1] Artificial brain '10 years away' 2009 BBC news (http://news.bbc.co.uk/1/hi/technology/8164060.stm)

[2] Kurzweil, Ray (2005), *The Singularity is Near*, Viking Press

[3] Aston University's news report about the project (http://www1.aston.ac.uk/about/news/releases/2009/march/scientists-create-living-model-of-basic-units-of-human-brain/)

[4] The critics:

- Searle, John (1980), "Minds, Brains and Programs" (http://web.archive.org/web/20071210043312/http://members.aol.com/NeoNoetics/MindsBrainsPrograms.html), *Behavioral and Brain Sciences* **3** (3): 417–457, doi:10.1017/S0140525X00005756, , retrieved May 13, 2009
- Dreyfus, Hubert (1972), *What Computers Can't Do*, New York: MIT Press, ISBN 0-06-090613-8
- Penrose, Roger (1989), *The Emperor's New Mind: Concerning Computers, Minds, and The Laws of Physics*, Oxford University Press, ISBN 0-14-014534-6

Turing's (pre-emptive) response:

- Turing, Alan (October 1950), "Computing Machinery and Intelligence" (http://loebner.net/Prizef/TuringArticle.html), *Mind* **LIX** (236): 433–460, doi:10.1093/mind/LIX.236.433, ISSN 0026-4423, , retrieved 2008-08-18

Other sources that agree with Turing:

- Moravec, Hans (1988), *Mind Children*, Harvard University Press
- Kurzweil, Ray (2005), *The Singularity is Near*, New York: Viking Press, ISBN 0-670-03384-7.

[5] Voss, Peter (2006), Goertzel, Ben; Pennachin, Cassio, eds., Essentials of general intelligence *Artificial General Intelligence* (http://www.adaptiveai.com/research/index.htm#different_approach), Springer, ISBN 3-540-23733-X, Essentials of general intelligence

[6] see Artificial Intelligence System, CAM brain machine (http://portal.acm.org/citation.cfm?id=591856) and cat brain for examples

[7] Jung, Sung Young, "A Topographical Development Method of Neural Networks for Artificial Brain Evolution" (http://mitpress.mit.edu/catalog/item/default.asp?ttype=6&tid=18358), *Artificial Life*, The MIT Press, vol. 11, issue 3 - summer, 2005, pp. 293-316

[8] Blue Brain in BBC News (http://newsvote.bbc.co.uk/mpapps/pagetools/print/news.bbc.co.uk/2/hi/science/nature/7740484.stm?ad=1)

[9] **(English)** *Out of the blue* (http://seedmagazine.com/content/article/out_of_the_blue/)

[10] **(English)** Jaap Bloem, Menno van Doorn, Sander Duivestein, Me the media: rise of the conversation society, VINT research Institute of Sogeti, 2009, p.273.

[11] Goertzel, Ben (Dec 2007). "Human-level artificial general intelligence and the possibility of a technological singularity: a reaction to Ray Kurzweil's *The Singularity Is Near*, and McDermott's critique of Kurzweil" (http://scholar.google.com/scholar?hl=sv&lr=&cluster=15189798216526465792). *Artificial Intelligence* **171** (18, Special Review Issue): 1161–1173. doi:10.1016/j.artint.2007.10.011. . Retrieved 1 April 2009.

[12] Fox and Hayes quoted in Nilsson, Nils (1998), Artificial Intelligence: A New Synthesis, p581 Morgan Kaufmann Publishers, ISBN 978-1-55860-467-4
[13] http://dobrev.com/AI/definition.html

External links

- Holographic Neural Technology (HNeT) (http://www.andcorporation.com/)
- http://www.artificialbrains.com
- Kurzweil AI.net (http://www.kurzweilai.net/meme/frame.html?m=3)

Artificial life

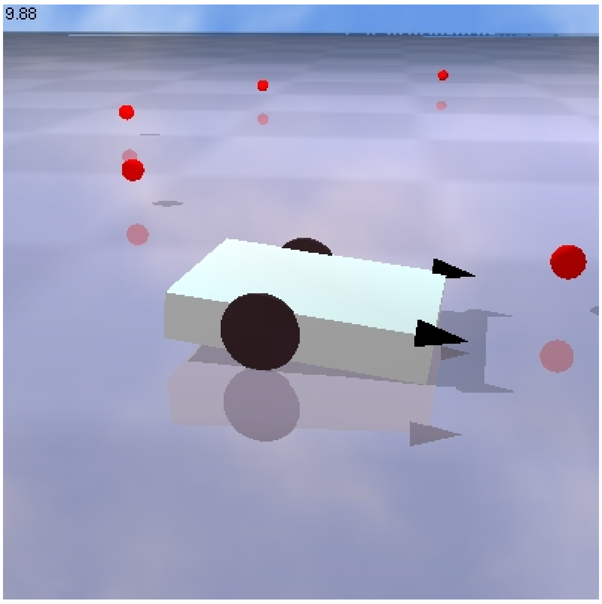
Artificial life (often abbreviated **ALife** or **A-Life**[1]) is a field of study and an associated art form which examine systems related to life, its processes, and its evolution through simulations using computer models, robotics, and biochemistry.[2] The discipline was named by Christopher Langton, an American computer scientist, in 1986.[3] There are three main kinds of alife,[4] named for their approaches: *soft*,[5] from software; *hard*,[6] from hardware; and *wet*, from biochemistry. Artificial life imitates traditional biology by trying to *recreate* some aspects of biological phenomena.[7] The term "artificial intelligence" is often used to specifically refer to soft alife.[8]

Overview

Artificial life studies the logic of living systems in artificial environments. The goal is to study the phenomena of living systems in order to come to an understanding of the complex information processing that defines such systems.

Also sometimes included in the umbrella term Artificial Life are agent based systems which are used to study the emergent properties of societies of agents.

While life is, by definition, alive, artificial life is generally referred to as being confined to a digital environment and existence.



A Braitenberg simulation, programmed in breve, an artificial life simulator

Philosophy

The modeling philosophy of alife strongly differs from traditional modeling, by studying not only “life-as-we-know-it”, but also “life-as-it-might-be”.[9]

In the first approach, a traditional model of a biological system will focus on capturing its most important parameters. In contrast, an alife modeling approach will generally seek to decipher the most simple and general principles underlying life and implement them in a simulation. The simulation then offers the possibility to analyse new, different lifelike systems.

Red'ko proposed to generalize this distinction not just to the modeling of life, but to any process. This led to the more general distinction of "processes-as-we-know-them" and "processes-as-they-could-be" [10]

At present, the commonly accepted definition of life does not consider any current alife simulations or softwares to be alive, and they do not constitute part of the evolutionary process of any ecosystem. However, different opinions about artificial life's potential have arisen:

- The *strong alife* (cf. Strong AI) position states that "life is a process which can be abstracted away from any particular medium" (John von Neumann). Notably, Tom Ray declared that his program Tierra is not simulating life in a computer but synthesizing it.
- The *weak alife* position denies the possibility of generating a "living process" outside of a chemical solution. Its researchers try instead to simulate life processes to understand the underlying mechanics of biological phenomena.

Software-based - "soft"

Techniques

- Cellular automata were used in the early days of artificial life, and they are still often used for ease of scalability and parallelization. Alife and cellular automata share a closely tied history.
- Neural networks are sometimes used to model the brain of an agent. Although traditionally more of an artificial intelligence technique, neural nets can be important for simulating population dynamics of organisms that can *learn*. The symbiosis between learning and evolution is central to theories about the development of instincts in organisms with higher neurological complexity, as in, for instance, the Baldwin effect.

Notable simulators

This is a list of artificial life/digital organism simulators, organized by the method of creature definition.

Name	Driven By	Started	Ended
Aevol	translatable dna	2003	NA
Avida	executable dna	1993	NA
breve	executable dna	2006	NA
Creatures	neural net	mid-1990s	
Darwinbots	executable dna	2003	
DigiHive	executable dna	2006	2009
EcoSim	Fuzzy Cognitive Map	2009	NA
Evolve 4.0	executable dna	1996	2007
Framsticks	executable dna	1996	NA
Primordial life	executable dna	1996	2003
TechnoSphere	modules		
Tierra	executable dna	early 1990s	?
Physis [11]	executable dna	2003	
Noble Ape	neural net	1996	NA
Polyworld	neural net		
3D Virtual Creature Evolution	neural net		NA

Program-based

Further information: programming game

These contain organisms with a complex DNA language, usually Turing complete. This language is more often in the form of a computer program than actual biological DNA. Assembly derivatives are the most common languages used. Use of cellular automata is common but not required.

Module-based

Individual modules are added to a creature. These modules modify the creature's behaviors and characteristics either directly, by hard coding into the simulation (leg type A increases speed and metabolism), or indirectly, through the emergent interactions between a creature's modules (leg type A moves up and down with a frequency of X, which interacts with other legs to create motion). Generally these are simulators which emphasize user creation and accessibility over mutation and evolution.

Parameter-based

Organisms are generally constructed with pre-defined and fixed behaviors that are controlled by various parameters that mutate. That is, each organism contains a collection of numbers or other *finite* parameters. Each parameter controls one or several aspects of an organism in a well-defined way.

Neural net–based

These simulations have creatures that learn and grow using neural nets or a close derivative. Emphasis is often, although not always, more on learning than on natural selection.

Hardware-based - "hard"

Further information: Robot

Hardware-based artificial life mainly consist of *robots*, that is, automatically guided machines, able to do tasks on their own.

Biochemical-based - "wet"

Further information: Synthetic life and Synthetic biology

Biochemical-based life is studied in the field of synthetic biology. It involves e.g. the creation of synthetic DNA. The term "wet" is an extension of the term "wetware".

Related subjects

1. Artificial intelligence has traditionally used a top down approach, while alife generally works from the bottom up.[12]
2. Artificial chemistry started as a method within the alife community to abstract the processes of chemical reactions.
3. Evolutionary algorithms are a practical application of the weak alife principle applied to optimization problems. Many optimization algorithms have been crafted which borrow from or closely mirror alife techniques. The primary difference lies in explicitly defining the fitness of an agent by its ability to solve a problem, instead of its ability to find food, reproduce, or avoid death. The following is a list of evolutionary algorithms closely related to and used in alife:
    - Ant colony optimization
    - Evolutionary algorithm
    - Genetic algorithm

  - Genetic programming
  - Swarm intelligence
4. Evolutionary art uses techniques and methods from artificial life to create new forms of art.
5. Evolutionary music uses similar techniques, but applied to music instead of visual art.
6. Abiogenesis and the origin of life sometimes employ alife methodologies as well.

Criticism

Alife has had a controversial history. John Maynard Smith criticized certain artificial life work in 1994 as "fact-free science".[13] However, the recent publication of artificial life articles in widely read journals such as *Science* and *Nature* is evidence that artificial life techniques are becoming more accepted in the mainstream, at least as a method of studying evolution.[14]

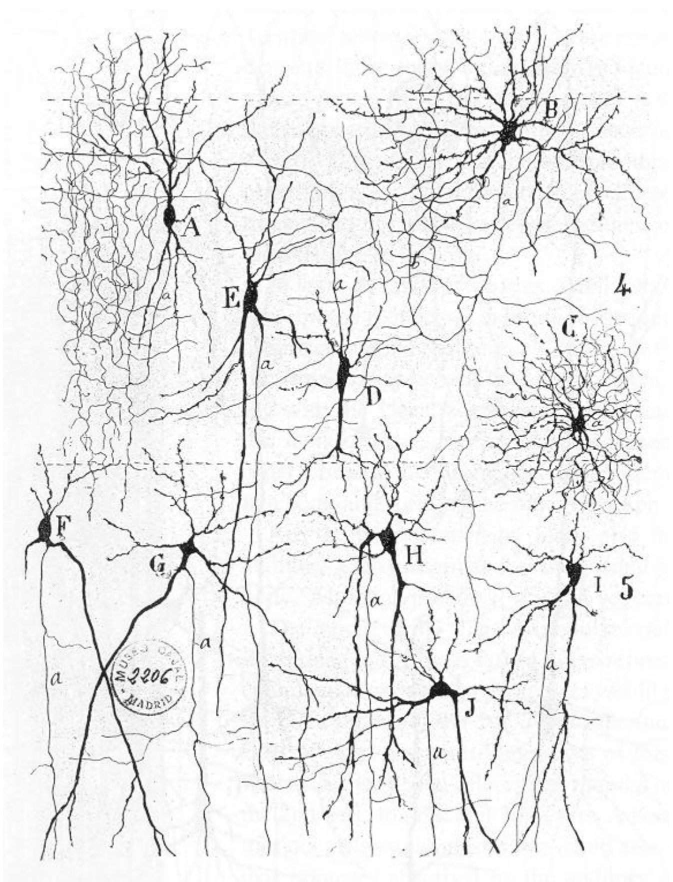
References

[1] Molecules and Thoughts Y Tarnopolsky - 2003 "Artificial Life (often abbreviated as Alife or A-life) is a small universe existing parallel to the much larger Artificial Intelligence. The origins of both areas were different."
[2] "Dictionary.com definition" (http://dictionary.reference.com/browse/artificial life). . Retrieved 2007-01-19.
[3] The MIT Encyclopedia of the Cognitive Sciences (http://books.google.com/books?id=-wt1aZrGXLYC&pg=PA37&cd=1#v=onepage), The MIT Press, p.37. ISBN 978-0-262-73144-7
[4] Mark A. Bedau (November 2003). "Artificial life: organization, adaptation and complexity from the bottom up" (http://www.reed.edu/~mab/publications/papers/BedauTICS03.pdf) (PDF). TRENDS in Cognitive Sciences. . Retrieved 2007-01-19.
[5] Maciej Komosinski and Andrew Adamatzky (2009). *Artificial Life Models in Software* (http://www.springer.com/computer/mathematics/book/978-1-84882-284-9). New York: Springer. ISBN 978-1-84882-284-9. .
[6] Andrew Adamatzky and Maciej Komosinski (2009). *Artificial Life Models in Hardware* (http://www.springer.com/computer/hardware/book/978-1-84882-529-1). New York: Springer. ISBN 978-1-84882-529-1. .
[7] Langton, Christopher. "What is Artificial Life?" (http://zooland.alife.org/). Archived (http://web.archive.org/web/20070117220840/http://zooland.alife.org/) from the original on 17 January 2007. . Retrieved 2007-01-19.
[8] John Johnston, (2008) "The Allure of Machinic Life: Cybernetics, Artificial Life, and the New AI", MIT Press
[9] See Langton, C. G. 1992. Artificial Life (http://www.probelog.com/texts/Langton_al.pdf). Addison-Wesley. ., section 1
[10] See Red'ko, V. G. 1999. Mathematical Modeling of Evolution (http://pespmc1.vub.ac.be/MATHME.html). in: F. Heylighen, C. Joslyn and V. Turchin (editors): Principia Cybernetica Web (Principia Cybernetica, Brussels). For the importance of ALife modeling from a cosmic perspective, see also Vidal, C. 2008. The Future of Scientific Simulations: from Artificial Life to Artificial Cosmogenesis (http://arxiv.org/abs/0803.1087). In Death And Anti-Death, ed. Charles Tandy, 6: Thirty Years After Kurt Gödel (1906-1978) p. 285-318. Ria University Press.)
[11] http://physis.sourceforge.net
[12] "AI Beyond Computer Games" (http://web.archive.org/web/20080701040911/http://www.lggwg.com/wolff/aicg99/stern.html). Archived from the original (http://lggwg.com/wolff/aicg99/stern.html) on 2008-07-01. . Retrieved 2008-07-04.
[13] Horgan, J. 1995. From Complexity to Perplexity. Scientific American. p107
[14] "Evolution experiments with digital organisms" (http://myxo.css.msu.edu/cgi-bin/lenski/prefman.pl?group=al). Archived (http://web.archive.org/web/20070212201846/http://myxo.css.msu.edu/cgi-bin/lenski/prefman.pl?group=al) from the original on 12 February 2007. . Retrieved 2007-01-19.

External links

- Computers: Artificial Life (http://www.dmoz.org/Computers/Artificial_Life/) at the open directory project
- Computers: Artificial Life Framework (http://www.artificiallife.org/)
- International Society of Artificial Life (http://alife.org/)
- Artificial Life (http://www.mitpressjournals.org/loi/artl) MIT Press Journal
- The Artificial Life Lab (http://www.envirtech.com/artificial-life-lab.html) Envirtech Island, Second Life
- aDiatomea: an artificial life experiment using highly detailed 3d generated diatoms (http://www.mrkism.com/diatomea/)

Biological neural network



From "Texture of the Nervous System of Man and the Vertebrates" by Santiago Ramón y Cajal. The figure illustrates the diversity of neuronal morphologies in the auditory cortex.

In neuroscience, a **biological neural network** (sometimes called a neural pathway) is a series of interconnected neurons whose activation defines a recognizable linear pathway. The interface through which neurons interact with their neighbors usually consists of several axon terminals connected via synapses to dendrites on other neurons. If the sum of the input signals into one neuron surpasses a certain threshold, the neuron sends an action potential (AP) at the axon hillock and transmits this electrical signal along the axon.

In contrast, a **neural circuit** is a functional entity of interconnected neurons that is able to regulate its own activity using a feedback loop (similar to a control loop in cybernetics).

Early study

Early treatments of neural networks can be found in Herbert Spencer's *Principles of Psychology*, 3rd edition (1872), Theodor Meynert's *Psychiatry* (1884), William James' *Principles of Psychology* (1890), and Sigmund Freud's Project for a Scientific Psychology (composed 1895). The first rule of neuronal learning was described by Hebb in 1949, Hebbian learning. Thus, Hebbian pairing of pre-synaptic and post-synaptic activity can substantially alter the dynamic characteristics of the synaptic connection and therefore facilitate or inhibit signal transmission. The neuroscientists Warren Sturgis McCulloch and Walter Pitts published the first works on the processing of neural networks called "What the frog's eye tells to the frog's brain." They showed theoretically that networks of artificial neurons could implement logical, arithmetic, and symbolic functions. Simplified models of biological neurons were set up, now usually called perceptrons or artificial neurons. These simple models accounted for neural summation (i.e., potentials at the post-synaptic membrane will summate in the cell body). Later models also provided for excitatory and inhibitory synaptic transmission.

Connections between neurons

The connections between neurons are much more complex than those implemented in neural computing architectures. The basic kinds of connections between neurons are chemical synapses and electrical gap junctions. One principle by which neurons work is neural summation, i.e. potentials at the post synaptic membrane will sum up in the cell body. If the depolarization of the neuron at the axon goes above threshold an action potential will occur that travels down the axon to the terminal endings to transmit a signal to other neurons. Excitatory and inhibitory synaptic transmission is realized mostly by inhibitory postsynaptic potentials and excitatory postsynaptic potentials.

On the electrophysiological level, there are various phenomena which alter the response characteristics of individual synapses (called synaptic plasticity) and individual neurons (intrinsic plasticity). These are often divided into short-term plasticity and long-term plasticity. Long-term synaptic plasticity is often contended to be the most likely memory substrate. Usually the term "neuroplasticity" refers to changes in the brain that are caused by activity or experience.

Connections display temporal and spatial characteristics. Temporal characteristics refer to the continuously modified activity-dependent efficacy of synaptic transmission, called spike-dependent synaptic plasticity. It has been observed in several studies that the synaptic efficacy of this transmission can undergo short-term increase (called facilitation) or decrease (depression) according to the activity of the presynaptic neuron. The induction of long-term changes in synaptic efficacy, by long-term potentiation (LTP) or depression (LTD), depends strongly on the relative timing of the onset of the excitatory postsynaptic potential and the postsynaptic action potential. LTP is induced by a series of action potentials which cause a variety of biochemical responses. Eventually, the reactions cause the expression of new receptors on the cellular membranes of the postsynaptic neurons or increase the efficacy of the existing receptors through phosphorylation.

Backpropagating action potentials cannot occur because after an action potential travels down a given segment of the axon, the voltage gated sodium channels' (Na+ channels) m gate becomes closed, thus blocking any transient opening of the h gate from causing a change in the intracellular [Na^+], and preventing the generation of an action potential back towards the cell body. In some cells, however, neural backpropagation does occur through the dendritic arbor and may have important effects on synaptic plasticity and computation.

A neuron in the brain requires a single signal to a neuromuscular junction to stimulate contraction of the postsynaptic muscle cell. In the spinal cord, however, at least 75 afferent neurons are required to produce firing. This picture is further complicated by variation in time constant between neurons, as some cells can experience their EPSPs over a wider period of time than others.

While in synapses in the developing brain synaptic depression has been particularly widely observed it has been speculated that it changes to facilitation in adult brains.

Representations in neural networks

A receptive field is a small region within the entire visual field. Any given neuron only responds to a subset of stimuli within its receptive field. This property is called tuning. As for vision, in the earlier visual areas, neurons have simpler tuning. For example, a neuron in V1 may fire to any vertical stimulus in its receptive field. In the higher visual areas, neurons have complex tuning. For example, in the fusiform gyrus, a neuron may only fire when a certain face appears in its receptive field. It is also known that many parts of the brain generate patterns of electrical activity that correspond closely to the layout of the retinal image (this is known as retinotopy). It seems further that imagery that originates from the senses and internally generated imagery may have a shared ontology at higher levels of cortical processing (see e.g. Language of thought). About many parts of the brain some characterization has been made as to what tasks are correlated with its activity.

In the brain, memories are very likely represented by patterns of activation amongst networks of neurons. However, how these representations are formed, retrieved and reach conscious awareness is not completely understood. Cognitive processes that characterize human intelligence are mainly ascribed to the emergent properties of complex dynamic characteristics in the complex systems that constitute neural networks. Therefore, the study and modeling of these networks have attracted broad interest under different paradigms and many different theories have been formulated to explain various aspects of their behavior. One of these — and the subject of several theories — is considered a special property of a neural network: the ability to learn complex patterns.

Philosophical issues

Today most researchers believe in mental representations of some kind (representationalism) or, more general, in particular mental states (cognitivism). For instance, perception can be viewed as information processing through transfer information from the world into the brain/mind where it is further processed and related to other information (cognitive processes). Few others envisage a direct path back into the external world in the form of action (radical behaviorism).

Another issue, called the binding problem, relates to the question of how the activity of more or less distinct populations of neurons dealing with different aspects of perception are combined to form a unified perceptual experience and have qualia.

Neuronal networks are not full reconstructions of any cognitive system found in the human brain, and are therefore unlikely to form a complete representation of human perception. Some researchers argue that human perception must be studied as a whole; hence, the system cannot be taken apart and studied without destroying its original functionality. Furthermore, there is evidence that cognition is gained through a well-orchestrated barrage of sub-threshold synaptic activity throughout the network.

Study methods

Different neuroimaging techniques have been developed to investigate the activity of neural networks. The use of "brain scanners" or functional neuroimaging to investigate the structure or function of the brain is common, either as simply a way of better assessing brain injury with high resolution pictures, or by examining the relative activations of different brain areas. Such technologies may include fMRI (functional magnetic resonance imaging), PET (positron emission tomography) and CAT (computed axial tomography). Functional neuroimaging uses specific brain imaging technologies to take scans from the brain, usually when a person is doing a particular task, in an attempt to understand how the activation of particular brain areas is related to the task. In functional neuroimaging, especially fMRI, which measures hemodynamic activity that is closely linked to neural activity, PET, and electroencephalography (EEG) is used.

Connectionist models serve as a test platform for different hypotheses of representation, information processing, and signal transmission. Lesioning studies in such models, e.g. artificial neural networks, where parts of the nodes are deliberately destroyed to see how the network performs, can also yield important insights in the working of several cell assemblies. Similarly, simulations of dysfunctional neurotransmitters in neurological conditions (e.g., dopamine in the basal ganglia of Parkinson's patients) can yield insights into the underlying mechanisms for patterns of cognitive deficits observed in the particular patient group. Predictions from these models can be tested in patients and/or via pharmacological manipulations, and these studies can in turn be used to inform the models, making the process recursive.

External links

- Learning, Memory and Plasticity [1]
- Comparison of Neural Networks in the Brain and Artificial Neural Networks [2]
- Lecture notes at MIT OpenCourseWare [3]
- Computation in the Brain [4]
- Signaling Properties of the Neuron [5]
- The Problem of Neuronal Coding [6]
- Biological Neural Network Toolbox [7] - A free Matlab toolbox for simulating networks of several different types of neurons
- WormWeb.org: Interactive Visualization of the C. elegans Neural Network [8] - C. elegans, a nematode with 302 neurons, is the only organism for whom the entire neural network has been uncovered. Use this site to browse

through the network and to search for paths between any 2 neurons.
- Introduction to Neurons and Neuronal Networks [9], *Neuroscience Online* (electronic neuroscience textbook)

References

[1] http://www.benbest.com/science/anatmind/anatmd3.html
[2] http://www.his.sunderland.ac.uk/ps/worksh2/denham.pdf
[3] http://ocw.mit.edu/OcwWeb/Brain-and-Cognitive-Sciences/9-95-AResearch-Topics-in-NeuroscienceJanuary--IAP-2003/LectureNotes/
[4] http://www.willamette.edu/~gorr/classes/cs449/brain.html
[5] http://ifcsun1.ifisiol.unam.mx/Brain/neuron2.htm
[6] http://diwww.epfl.ch/~gerstner/SPNM/node6.html
[7] http://www.ymer.org/amir/software/biological-neural-networks-toolbox/
[8] http://wormweb.org/neuralnet.html
[9] http://nba.uth.tmc.edu/neuroscience/s1/introduction.html

Cybernetics

Cybernetics is a transdisciplinary[1] approach for exploring regulatory systems, their structures, constraints, and possibilities. Cybernetics is relevant to the study of mechanical, physical, biological, cognitive, and social systems. Cybernetics is only applicable when the system being analysed is involved in a closed signal loop; that is, where action by the system causes some change in its environment and that change is fed to the system via information (feedback) that enables the system to change its behavior. This "circular causal" relationship is necessary and sufficient for a cybernetic perspective. System Dynamics, a related field, originated with applications of electrical engineering control theory to other kinds of simulation models (especially business systems) by Jay Forrester at MIT in the 1950s.

Concepts studied by cyberneticists (or, as some prefer, cyberneticians) include, but are not limited to: learning, cognition, adaption, social control, emergence, communication, efficiency, efficacy, and connectivity. These concepts are studied by other subjects such as engineering and biology, but in cybernetics these are removed from the context of the individual organism or device.

Cybernetics was defined in the mid 20th century, by Norbert Wiener as "the scientific study of control and communication in the animal and the machine."[2] Cybernetics from the Greek meaning to "steer" or "navigate." Contemporary cybernetics began as an interdisciplinary study connecting the fields of control systems, electrical network theory, mechanical engineering, logic modeling, evolutionary biology, neuroscience, anthropology, and psychology in the 1940s, often attributed to the Macy Conferences. During the second half of the 20th century cybernetics evolved in ways that distinguish first-order cybernetics (about observed systems) from second-order cybernetics (about observing systems).[3] More recently there is talk about a third-order cybernetics (doing in ways that embraces first and second-order).[4]

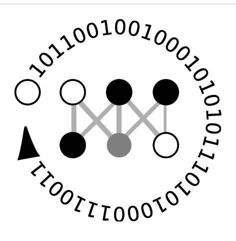
Fields of study which have influenced or been influenced by cybernetics include game theory, system theory (a mathematical counterpart to cybernetics), perceptual control theory, sociology, psychology (especially neuropsychology, behavioral psychology, cognitive psychology), philosophy, architecture, and organizational theory.[5]

Definitions

Cybernetics has been defined in a variety ways, by a variety of people, from a variety of disciplines. The *Larry Richards Reader* includes a list of definitions:[6]

- "Science concerned with the study of systems of any nature which are capable of receiving, storing and processing information so as to use it for control."—A. N. Kolmogorov
- "The art of securing efficient operation."—L. Couffignal
- "'The art of steersmanship': deals with all forms of behavior in so far as they are regular, or determinate, or reproducible: stands to the real machine -- electronic, mechanical, neural, or economic -- much as geometry stands to real object in our terrestrial space; offers a method for the scientific treatment of the system in which complexity is outstanding and too important to be ignored."—W. Ross Ashby
- "A branch of mathematics dealing with problems of control, recursiveness, and information, focuses on forms and the patterns that connect."—Gregory Bateson
- "The art of effective organization."—Stafford Beer
- "The art and science of manipulating defensible metaphors."—Gordon Pask
- "The art of creating equilibrium in a world of constraints and possibilities."—Ernst von Glasersfeld
- "The science and art of understanding."—Humberto Maturana
- "The ability to cure all temporary truth of eternal triteness."—Herbert Brun
- "The science and art of the understanding of understanding."—Rodney E. Donaldson
- "A way of thinking about ways of thinking of which it is one."—Larry Richards
- "The art of interaction in dynamic networks." - Roy Ascott

Etymology



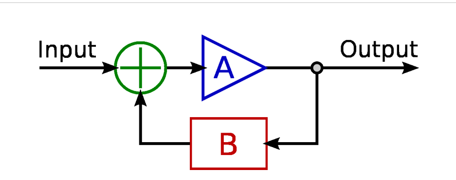


Figure 1: Ideal feedback model. The system is negative and stable if B < 0

The term *cybernetics* stems from Ancient Greek *κυβερνήτης (kybernētēs)*, meaning "steersman, governor, pilot, or rudder" (the same root as *government*). As with the ancient Greek pilot, independence of thought is important in cybernetics.[7] Cybernetics is a broad field of study, but the essential goal of cybernetics is to understand and define the functions and processes of systems that have goals and that participate in circular, causal chains that move from action to sensing to comparison with desired goal, and again to action. Studies in cybernetics provide a means for examining the design and function of any system, including social systems such as business management and organizational learning, including for the purpose of making them more efficient and effective.

French physicist and mathematician André-Marie Ampère first coined the word "cybernetique" in his 1845 essay *Essai ur la philosophie des sciences* to describe the science of civil goverment[8].

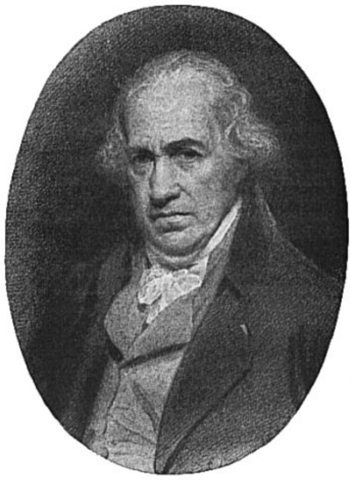
Cybernetics was borrowed by Norbert Wiener, in his book "Cybernetics", to define the study of control and communication in the animal and the machine[9]. Stafford Beer called it the science of effective organization and Gordon Pask called it "the art of defensible metaphors" (emphasizing its constructivist epistemology) though he later extended it to include information flows "in all media" from stars to brains. It includes the study of feedback, black boxes and derived concepts such as communication and control in living organisms, machines and organizations including self-organization. Its focus is how anything (digital, mechanical or biological) processes information,

reacts to information, and changes or can be changed to better accomplish the first two tasks.[10] A more philosophical definition, suggested in 1956 by Louis Couffignal, one of the pioneers of cybernetics, characterizes cybernetics as "the art of ensuring the efficacy of action."[11] The most recent definition has been proposed by Louis Kauffman, President of the American Society for Cybernetics, "Cybernetics is the study of systems and processes that interact with themselves and produce themselves from themselves."[12]

History

The roots of cybernetic theory

The word *cybernetics* was first used in the context of "the study of self-governance" by Plato in The Alcibiades to signify the governance of people.[13] The word 'cybernétique' was also used in 1834 by the physicist André-Marie Ampère (1775–1836) to denote the sciences of government in his classification system of human knowledge.



James Watt

The first artificial automatic regulatory system, a water clock, was invented by the mechanician Ktesibios. In his water clocks, water flowed from a source such as a holding tank into a reservoir, then from the reservoir to the mechanisms of the clock. Ktesibios's device used a cone-shaped float to monitor the level of the water in its reservoir and adjust the rate of flow of the water accordingly to maintain a constant level of water in the reservoir, so that it neither overflowed nor was allowed to run dry. This was the first artificial truly automatic self-regulatory device that required no outside intervention between the feedback and the controls of the mechanism. Although they did not refer to this concept by the name of Cybernetics (they considered it a field of engineering), Ktesibios and others such as Heron and Su Song are considered to be some of the first to study cybernetic principles.

The study of *teleological mechanisms* (from the Greek τέλος or *telos* for *end*, *goal*, or *purpose*) in machines with *corrective feedback* dates from as far back as the late 18th century when James Watt's steam engine was equipped with a governor, a centrifugal feedback valve for controlling the speed of the engine. Alfred Russel Wallace identified this as the principle of evolution in his famous 1858 paper. In 1868 James Clerk Maxwell published a theoretical article on governors, one of the first to discuss and refine the principles of self-regulating devices. Jakob von Uexküll applied the feedback mechanism via his model of functional cycle (*Funktionskreis*) in order to explain animal behaviour and the origins of meaning in general.

The early 20th century

Contemporary cybernetics began as an interdisciplinary study connecting the fields of control systems, electrical network theory, mechanical engineering, logic modeling, evolutionary biology and neuroscience in the 1940s. Electronic control systems originated with the 1927 work of Bell Telephone Laboratories engineer Harold S. Black on using negative feedback to control amplifiers. The ideas are also related to the biological work of Ludwig von Bertalanffy in General Systems Theory.

Early applications of negative feedback in electronic circuits included the control of gun mounts and radar antenna during World War II. Jay Forrester, a graduate student at the Servomechanisms Laboratory at MIT during WWII working with Gordon S. Brown to develop electronic control systems for the U.S. Navy, later applied these ideas to social organizations such as corporations and cities as an original organizer of the MIT School of Industrial Management at the MIT Sloan School of Management. Forrester is known as the founder of System Dynamics.

W. Edwards Deming, the Total Quality Management guru for whom Japan named its top post-WWII industrial prize, was an intern at Bell Telephone Labs in 1927 and may have been influenced by network theory. Deming made "Understanding Systems" one of the four pillars of what he described as "Profound Knowledge" in his book "The New Economics."

Numerous papers spearheaded the coalescing of the field. In 1935 Russian physiologist P.K. Anokhin published a book in which the concept of feedback ("back afferentation") was studied. The study and mathematical modelling of regulatory processes became a continuing research effort and two key articles were published in 1943. These papers were "Behavior, Purpose and Teleology" by Arturo Rosenblueth, Norbert Wiener, and Julian Bigelow; and the paper "A Logical Calculus of the Ideas Immanent in Nervous Activity" by Warren McCulloch and Walter Pitts.

Cybernetics as a discipline was firmly established by Norbert Wiener, McCulloch and others, such as W. Ross Ashby, mathematician Alan Turing, and W. Grey Walter. Walter was one of the first to build autonomous robots as an aid to the study of animal behaviour. Together with the US and UK, an important geographical locus of early cybernetics was France.

In the spring of 1947, Wiener was invited to a congress on harmonic analysis, held in Nancy, France. The event was organized by the Bourbaki, a French scientific society, and mathematician Szolem Mandelbrojt (1899–1983), uncle of the world-famous mathematician Benoît Mandelbrot.


John von Neumann

During this stay in France, Wiener received the offer to write a manuscript on the unifying character of this part of applied mathematics, which is found in the study of Brownian motion and in telecommunication engineering. The following summer, back in the United States, Wiener decided to introduce the neologism cybernetics into his scientific theory. The name *cybernetics* was coined to denote the study of "teleological mechanisms" and was popularized through his book *Cybernetics, or Control and Communication in the Animal and Machine* (MIT Press/John Wiley and Sons, NY, 1948). In the UK this became the focus for the Ratio Club.

In the early 1940s John von Neumann, although better known for his work in mathematics and computer science, did contribute a unique and unusual addition to the world of cybernetics: Von Neumann cellular automata, and their logical follow up the Von Neumann Universal Constructor. The result of these deceptively simple thought-experiments was the concept of self replication which cybernetics adopted as a core concept. The concept that the same properties of genetic reproduction applied to social memes, living cells, and even computer viruses is further proof of the somewhat surprising universality of cybernetic study.

Wiener popularized the social implications of cybernetics, drawing analogies between automatic systems (such as a regulated steam engine) and human institutions in his best-selling *The Human Use of Human Beings : Cybernetics and Society* (Houghton-Mifflin, 1950).

While not the only instance of a research organization focused on cybernetics, the Biological Computer Lab [14] at the University of Illinois, Urbana/Champaign, under the direction of Heinz von Foerster, was a major center of cybernetic research [15] for almost 20 years, beginning in 1958.

Split from artificial intelligence

Artificial intelligence (AI) was founded as a distinct discipline at a 1956 conference. After some uneasy coexistence, AI gained funding and prominence. Consequently, cybernetic sciences such the study of neural networks were downplayed; the discipline shifted into the world of social sciences and therapy.[16]

Gregory Bateson and Margaret Mead were prominent cyberneticians during this period.

New cybernetics

In the 1970s, new cyberneticians emerged in multiple fields, but especially in biology. The ideas of Maturana, Varela and Atlan, according to Dupuy (1986) "realized that the cybernetic metaphors of the program upon which molecular biology had been based rendered a conception of the autonomy of the living being impossible. Consequently, these thinkers were led to invent a new cybernetics, one more suited to the organizations which mankind discovers in nature - organizations he has not himself invented".[17] However, during the 1980s the question of whether the features of this new cybernetics could be applied to social forms of organization remained open to debate.[17]

In political science, Project Cybersyn attempted to introduce a cybernetically controlled economy during the early 1970s. In the 1980s, according to Harries-Jones (1988) "unlike its predecessor, the new cybernetics concerns itself with the interaction of autonomous political actors and subgroups, and the practical and reflexive consciousness of the subjects who produce and reproduce the structure of a political community. A dominant consideration is that of recursiveness, or self-reference of political action both with regards to the expression of political consciousness and with the ways in which systems build upon themselves".[18]

One characteristic of the emerging new cybernetics considered in that time by Geyer and van der Zouwen, according to Bailey (1994), was "that it views information as constructed and reconstructed by an individual interacting with the environment. This provides an epistemological foundation of science, by viewing it as observer-dependent. Another characteristic of the new cybernetics is its contribution towards bridging the "micro-macro gap". That is, it links the individual with the society".[19] Another characteristic noted was the "transition from classical cybernetics to the new cybernetics [that] involves a transition from classical problems to new problems. These shifts in thinking involve, among others, (a) a change from emphasis on the system being steered to the system doing the steering, and the factor which guides the steering decisions.; and (b) new emphasis on communication between several systems which are trying to steer each other".[19]

Recent endeavors into the true focus of cybernetics, systems of control and emergent behavior, by such related fields as game theory (the analysis of group interaction), systems of feedback in evolution, and metamaterials (the study of materials with properties beyond the Newtonian properties of their constituent atoms), have led to a revived interest in this increasingly relevant field.[10]

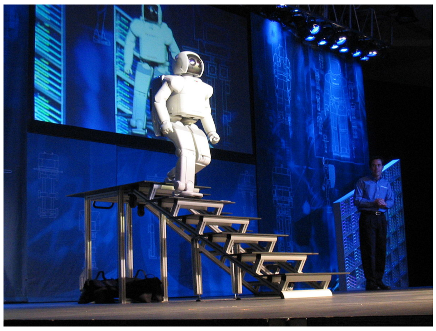
Subdivisions of the field

Cybernetics is sometimes used as a generic term, which serves as an umbrella for many systems-related scientific fields.

Basic cybernetics

Cybernetics studies systems of control as a concept, attempting to discover the basic principles underlying such things as

- Artificial intelligence
- Robotics
- Computer Vision
- Control systems
- Emergence
- Learning organization
- New Cybernetics
- Second-order cybernetics
- Interactions of Actors Theory
- Conversation Theory
- Self-organization in cybernetics



ASIMO uses sensors and sophisticated algorithms to avoid obstacles and navigate stairs.

In biology

Cybernetics in biology is the study of cybernetic systems present in biological organisms, primarily focusing on how animals adapt to their environment, and how information in the form of genes is passed from generation to generation.[20] There is also a secondary focus on combining artificial systems with biological systems.

- Bioengineering
- Biocybernetics
- Bionics
- Homeostasis
- Medical cybernetics
- Synthetic Biology
- Systems Biology
- Autopoiesis

In computer science

Computer science directly applies the concepts of cybernetics to the control of devices and the analysis of information.

- Design Patterns
- Robotics
- Decision support system
- Cellular automaton
- Simulation
- Technology

In engineering

Cybernetics in engineering is used to analyze cascading failures and System Accidents, in which the small errors and imperfections in a system can generate disasters. Other topics studied include:

- Adaptive systems
- Engineering cybernetics
- Ergonomics
- Biomedical engineering
- Systems engineering


An artificial heart, a product of biomedical engineering.

In management

- Entrepreneurial cybernetics
- Management cybernetics
- Organizational cybernetics

- Operations research
- Systems engineering

In mathematics

Mathematical Cybernetics focuses on the factors of information, interaction of parts in systems, and the structure of systems.

- Dynamical system
- Information theory
- Systems theory

In psychology

- Homunculus
- Psycho-Cybernetics
- Systems psychology
- Perceptual Control Theory
- Psychovector Analysis
- Attachment Theory
- Human-robot interaction
- Consciousness
- Embodied cognition
- Cognitive psychology
- Mind-body problem
- Behavioral cybernetics

In sociology

By examining group behavior through the lens of cybernetics, sociologists can seek the reasons for such spontaneous events as smart mobs and riots, as well as how communities develop rules such as etiquette by consensus without formal discussion. Affect Control Theory explains role behavior, emotions, and labeling theory in terms of homeostatic maintenance of sentiments associated with cultural categories. The most comprehensive attempt ever made in the social sciences to increase cybernetics in a generalized theory of society was made by Talcott Parsons. In this way, cybernetics establishes the basic hierarchy in Parsons' AGIL paradigm, which is the ordering system-dimension of his action theory. These and other cybernetic models in sociology are reviewed in a book edited

by McClelland and Fararo.[21]

- Affect Control Theory
- Memetics
- Sociocybernetics

In art

Nicolas Schöffer's *CYSP I* (1956) was perhaps the first artwork to explicitly employ cybernetic principles (CYSP is an acronym that joins the first two letters of the words "CYbernetic" and "SPatiodynamic").[22] The artist Roy Ascott elaborated an extensive theory of cybernetic art in "Behaviourist Art and the Cybernetic Vision" (Cybernetica, Journal of the International Association for Cybernetics (Namur), Volume IX, No.4, 1966; Volume X No.1, 1967) and in "The Cybernetic Stance: My Process and Purpose" (Leonardo Vol 1, No 2, 1968). Art historian Edward A. Shanken has written about the history of art and cybernetics in essays including "Cybernetics and Art: Cultural Convergence in the 1960s [23],[24] and "From Cybernetics to Telematics: The Art, Pedagogy, and Theory of Roy Ascott"(2003),[25] which traces the trajectory of Ascott's work from cybernetic art to telematic art (art using computer networking as its medium, a precursor to net.art.)

- Telematic art
- Interactive Art
- Systems art

In Earth system science

Geocybernetics aims to study and control the complex co-evolution of ecosphere and anthroposphere.[26]

Related fields

Complexity science

Complexity science attempts to understand the nature of complex systems.

- Complex Adaptive System
- Complex systems
- Complexity theory

References

[1] Müller, Albert (2000). "A Brief History of the BCL" (http://bcl.ece.illinois.edu/mueller/index.htm). *Österreichische Zeitschrift für Geschichtswissenschaften* **11** (1): 9–30. .
[2] Wiener, Norbert (1948). *Cybernetics, or Communication and Control in the Animal and the Machine*. Cambridge: MIT Press.
[3] Heinz von Foerster (1981), 'Observing Systems", Intersystems Publications, Seaside, CA. OCLC 263576422
[4] Kenny, Vincent (15 March 2009). "There's Nothing Like the Real Thing". Revisiting the Need for a Third-Order Cybernetics" (http://www.univie.ac.at/constructivism/journal/4/2/100.kenny). *Constructivist Foundations* **4** (2): 100–111. . Retrieved 6 June 2012.
[5] Tange, Kenzo (1966) "Function, Structure and Symbol".
[6] "Definitions of Cybernetics" (http://polyproject.wikispaces.com/file/view/Larry+Richards+Reader+6+08.pdf). *A Larry Richards Reader 1997–2007*. 2008. pp. 9–11. . "I developed this list of definitions/descriptions in 1987-88 and have been distributing it at ASC (American Society for Cybernetics)conferences since 1988. I added a few items to the list over the next two years, and it has remained essentially unchanged since then. My intent was twofold: (1) to demonstrate that one of the distinguishing features of cybernetics might be that it could legitimately have multiple definitions without contradicting itself, and (2) to stimulate dialogue on what the motivations (intentions, desires, etc.) of those who have proposed different definitions might be."
[7] Leary,Timothy. "The Cyberpunk: the individual as reality pilot" in Storming the Reality Studio. Duke University Press: 1991.
[8] H.S. TsienEngineering Cybernetics, Preface vii, 1954 McGraw Hill
[9] Norbert Wiener, Cybernetics or the control and communication in the animal and the machine, 1948 MIT Press
[10] Kelly, Kevin (1994). *Out of control: The new biology of machines, social systems and the economic world*. Boston: Addison-Wesley. ISBN 0-201-48340-8. OCLC 221860672 32208523 40868076 56082721 57396750.

[11] Couffignal, Louis, "Essai d'une définition générale de la cybernétique", *The First International Congress on Cybernetics*, Namur, Belgium, June 26–29, 1956, Gauthier-Villars, Paris, 1958, pp. 46-54
[12] CYBCON discusstion group 20 September 2007 18:15
[13] Johnson, Barnabas. "The Cybernetics of Society" (http://www.jurlandia.org/cybsoc.htm). . Retrieved 8 January 2012.
[14] http://www.ece.uiuc.edu/pubs/bcl/mueller/index.htm
[15] http://www.ece.uiuc.edu/pubs/bcl/hutchinson/index.htm
[16] Cariani, Peter (15 March 2010). "on the importance of being emergent" (http://www.univie.ac.at/constructivism/journal/5/2/086.cariani). *Constructivist Foundations* **5** (2): 89. . Retrieved 13 August 2012. "artificial intelligence was born at a conference at dartmouth in 1956 that was organized by McCarthy, Minsky, rochester, and shannon, three years after the Macy conferences on cybernetics had ended (Boden 2006; McCorduck 1972). The two movements coexisted for roughly a de- cade, but by the mid-1960s, the proponents of symbolic ai gained control of national funding conduits and ruthlessly defunded cybernetics research. This effectively liq- uidated the subfields of self-organizing systems, neural networks and adaptive ma- chines, evolutionary programming, biologi- cal computation, and bionics for several de- cades, leaving the workers in management, therapy and the social sciences to carry the torch. i think some of the polemical pushing-and-shoving between first-order control theorists and second-order crowds that i witnessed in subsequent decades was the cumulative result of a shift of funding, membership, and research from the "hard" natural sciences to "soft" socio-psychologi- cal interventions."
[17] Jean-Pierre Dupuy, "The autonomy of social reality: on the contribution of systems theory to the theory of society" in: Elias L. Khalil & Kenneth E. Boulding eds., *Evolution, Order and Complexity*, 1986.
[18] Peter Harries-Jones (1988), "The Self-Organizing Polity: An Epistemological Analysis of Political Life by Laurent Dobuzinskis" in: *Canadian Journal of Political Science* (Revue canadienne de science politique), Vol. 21, No. 2 (Jun., 1988), pp. 431-433.
[19] Kenneth D. Bailey (1994), *Sociology and the New Systems Theory: Toward a Theoretical Synthesis*, p.163.
[20] Note: this does not refer to the concept of Racial Memory but to the concept of cumulative adaptation to a particular niche, such as the case of the pepper moth having genes for both light and dark environments.
[21] McClelland, Kent A., and Thomas J. Fararo (Eds.). 2006. Purpose, Meaning, and Action: Control Systems Theories in Sociology. New York: Palgrave Macmillan.
[22] "CYSP I, the first cybernetic sculpture of art's history" (http://www.olats.org/schoffer/cyspe.htm). Leonardo/OLATS - Observatoire Leonardo des arts et des technosciences. .
[23] http://www.artexetra.com//CyberneticsArtCultConv.pdf
[24] Bruce Clarke and Linda Dalrymple Henderson, ed. (2002). *From Energy to Information: Representation in Science, Technology, Art, and Literature*. Stanford: Stanford University Press. pp. 255–277.
[25] Ascott, Roy (2003). Edward A. Shanken. ed. *Telematic Embrace: Visionary Theories of Art, Technology, and Consciousness*. Berkeley: University of California Press.
[26] Schellnhuber, H.-J., Discourse: Earth system analysis - The scope of the challenge, pp. 3-195. In: Schellnhuber, H.-J. and Wenzel, V. (Eds.). 1998. Earth system analysis: Integrating science for sustainability. Berlin: Springer.

Further reading

- Medina, Eden (2011). *Cybernetic revolutionaries : technology and politics in Allende's Chile*. Cambridge, Mass.: MIT Press. ISBN 978-0-262-01649-0.
- Pickering, Andrew (2010). *The cybernetic brain : sketches of another future* ([Online-Ausg.] ed.). Chicago: University of Chicago Press. ISBN 978-0226667898.
- Gerovitch, Slava (2002). *From newspeak to cyberspeak : a history of Soviet cybernetics* (http://web.mit.edu/slava/homepage/newspeak.htm). Cambridge, Mass. [u.a.]: MIT Press. ISBN 0262-07232-7.
- Johnston, John (2008). *The allure of machinic life : cybernetics, artificial life, and the new AI*. Cambridge, MA: MIT Press. ISBN 978-0-262-10126-4.
- Heikki Hyötyniemi (2006). *Neocybernetics in Biological Systems* (http://neocybernetics.com/report151/). Espoo: Helsinki University of Technology, Control Engineering Laboratory.
- Francis Heylighen, and Cliff Joslyn (2001). " Cybernetics and Second Order Cybernetics (http://pespmc1.vub.ac.be/Papers/Cybernetics-EPST.pdf)", in: R.A. Meyers (ed.), *Encyclopedia of Physical Science & Technology* (3rd ed.), Vol. 4, (Academic Press, New York), p. 155-170.
- Charles François (1999). " Systemics and cybernetics in a historical perspective (http://www.uni-klu.ac.at/~gossimit/ifsr/francois/papers/systemics_and_cybernetics_in_a_historical_perspective.pdf)". In: *Systems Research and Behavioral Science*. Vol 16, pp. 203–219 (1999)
- Heinz von Foerster, (1995), Ethics and Second-Order Cybernetics (http://www.stanford.edu/group/SHR/4-2/text/foerster.html).

- Heims, Steve Joshua (1993). *Constructing a social science for postwar America : the cybernetics group, 1946-1953* (1st ed.). Cambridge, Mass. u.a.: MIT Press. ISBN 9780262581233.
- Pangaro, Paul. "Cybernetics - A Definition" (http://pangaro.com/published/cyber-macmillan.html).
- Stuart Umpleby (1989), "The science of cybernetics and the cybernetics of science" (ftp://ftp.vub.ac.be/pub/projects/Principia_Cybernetica/Papers_Umpleby/Science-Cybernetics.txt), in: *Cybernetics and Systems", Vol. 21, No. 1, (1990), pp. 109–121.*
- Arbib, Michael A. (1987). *Brains, machines, and mathematics* (2nd ed.). New York: Springer-Verlag. ISBN 978-0387965390.
- Patten, Bernard C.; Odum, Eugene P. (December 1981). "The Cybernetic Nature of Ecosystems". *The American Naturalist* (The University of Chicago Press) **118** (6): 886–895. doi:10.1086/283881. JSTOR 2460822?.
- Hans Joachim Ilgauds (1980), *Norbert Wiener*, Leipzig.
- Beer, Stafford (1974). *Designing freedom*. Chichester, West Sussex, England: Wiley. ISBN 978-0471951650.
- Pask, Gordon (1972). "Cybernetics" (http://www.cybsoc.org/gcyb.htm). *Encyclopædia Britannica*.
- Helvey, T.C. (1971). *The age of information; an interdisciplinary survey of cybernetics*. Englewood Cliffs, N.J.: Educational Technology Publications. ISBN 9780877780083.
- Roy Ascott (1967). Behaviourist Art and the Cybernetic Vision. Cybernetica, Journal of the International Association for Cybernetics (Namur), 10, pp. 25–56
- William Ross Ashby (1956). *An introduction to cybernetics* (http://pespmc1.vub.ac.be/books/IntroCyb.pdf). Chapman & Hall. Retrieved 3 June 2012.
- Norbert Wiener (1948). Hermann & Cie. ed. *Cybernetics; or, Control and communication in the animal and the machine* (http://books.google.com/books?id=2AKaAAAAIAAJ). Paris: Technology Press. Retrieved 3 June 2012.

External links

General

- Norbert Wiener and Stefan Odobleja - A Comparative Analysis (http://www.bu.edu/wcp/Papers/Comp/CompJurc.htm)
- Reading List for Cybernetics (http://www.cscs.umich.edu/~crshalizi/notabene/cybernetics.html)
- *Principia Cybernetica Web* (http://pespmc1.vub.ac.be/DEFAULT.html)
- Web Dictionary of Cybernetics and Systems (http://pespmc1.vub.ac.be/ASC/indexASC.html)
- Glossary Slideshow (136 slides) (http://www.gwu.edu/~asc/slide/s1.html)
- Basics of Cybernetics (http://www.smithsrisca.demon.co.uk/cybernetics.html)
- What is Cybernetics? (http://www.youtube.com/watch?v=_hjAXkNbPfk) Livas short introductory videos on YouTube
- A History of Systemic and Cybernetic Thought. From Homeostasis to the Teardrop (http://www.pclibya.com/cybernetic_teardrop.pdf)

Societies

- American Society for Cybernetics (http://www.asc-cybernetics.org/)
- IEEE Systems, Man, & Cybernetics Society (http://www.ieeesmc.org/)
- International Society for Cybernetics and Systems Research (http://3rd-street.net/Group/index.php/index.php?topic=68.msg216#msg216)
- The Cybernetics Society (http://www.cybsoc.org)

Connectionism

Connectionism is a set of approaches in the fields of artificial intelligence, cognitive psychology, cognitive science, neuroscience, and philosophy of mind, that models mental or behavioral phenomena as the emergent processes of *interconnected networks of simple units*. There are many forms of connectionism, but the most common forms use neural network models.

Basic principles

The central connectionist principle is that mental phenomena can be described by interconnected networks of simple and often uniform units. The form of the connections and the units can vary from model to model. For example, units in the network could represent neurons and the connections could represent synapses.

Spreading activation

In most connectionist models, networks change over time. A closely related and very common aspect of connectionist models is *activation*. At any time, a unit in the network has an activation, which is a numerical value intended to represent some aspect of the unit. For example, if the units in the model are neurons, the activation could represent the probability that the neuron would generate an action potential spike. If the activation spreads to all the other units connected to it. Spreading activation is always a feature of neural network models, and it is very common in connectionist models used by cognitive psychologists.

Neural networks

Neural networks are by far the most commonly used connectionist model today.Though there are a large variety of neural network models, they almost always follow two basic principles regarding the mind:

1. Any mental state can be described as an (N)-dimensional vector of numeric activation values over neural units in a network.
2. Memory is created by modifying the strength of the connections between neural units. The connection strengths, or "weights", are generally represented as an (N×N)-dimensional matrix.

Most of the variety among neural network models comes from:

- *Interpretation of units*: Units can be interpreted as neurons or groups of neurons.
- *Definition of activation*: Activation can be defined in a variety of ways. For example, in a Boltzmann machine, the activation is interpreted as the probability of generating an action potential spike, and is determined via a logistic function on the sum of the inputs to a unit.
- *Learning algorithm*: Different networks modify their connections differently. In general, any mathematically defined change in connection weights over time is referred to as the "learning algorithm".

Connectionists are in agreement that recurrent neural networks (networks wherein connections of the network can form a directed cycle) are a better model of the brain than feedforward neural networks (networks with no directed cycles). Many recurrent connectionist models also incorporate dynamical systems theory. Many researchers, such as the connectionist Paul Smolensky, have argued that connectionist models will evolve toward fully continuous, high-dimensional, non-linear, dynamic systems approaches.

Biological realism

The neural network branch of connectionism suggests that the study of mental activity is really the study of neural systems. This links connectionism to neuroscience, and models involve varying degrees of biological realism. Connectionist work in general need not be biologically realistic, but some neural network researchers, computational neuroscientists, try to model the biological aspects of natural neural systems very closely in so-called "neuromorphic networks". Many authors find the clear link between neural activity and cognition to be an appealing aspect of connectionism. This has been criticized as reductionist.

Learning

Connectionists generally stress the importance of learning in their models. Thus, connectionists have created many sophisticated learning procedures for neural networks. Learning always involves modifying the connection weights. In general, these involve mathematical formulas to determine the change in weights when given sets of data consisting of activation vectors for some subset of the neural units.

By formalizing learning in such a way, connectionists have many tools. A very common strategy in connectionist learning methods is to incorporate gradient descent over an error surface in a space defined by the weight matrix. All gradient descent learning in connectionist models involves changing each weight by the partial derivative of the error surface with respect to the weight. Backpropagation, first made popular in the 1980s, is probably the most commonly known connectionist gradient descent algorithm today.

History

Connectionism can be traced to ideas more than a century old, which were little more than speculation until the mid-to-late 20th century. It wasn't until the 1980s that connectionism became a popular perspective among scientists.

Parallel distributed processing

The prevailing connectionist approach today was originally known as **parallel distributed processing** (PDP). It was an artificial neural network approach that stressed the parallel nature of neural processing, and the distributed nature of neural representations. It provided a general mathematical framework for researchers to operate in. The framework involved eight major aspects:

- A set of *processing units*, represented by a set of integers.
- An *activation* for each unit, represented by a vector of time-dependent functions.
- An *output function* for each unit, represented by a vector of functions on the activations.
- A *pattern of connectivity* among units, represented by a matrix of real numbers indicating connection strength.
- A *propagation rule* spreading the activations via the connections, represented by a function on the output of the units.
- An *activation rule* for combining inputs to a unit to determine its new activation, represented by a function on the current activation and propagation.
- A *learning rule* for modifying connections based on experience, represented by a change in the weights based on any number of variables.
- An *environment* that provides the system with experience, represented by sets of activation vectors for some subset of the units.

These aspects are now the foundation for almost all connectionist models. A perceived limitation of PDP is that it is reductionistic. That is, all cognitive processes can be explained in terms of neural firing and communication.

A lot of the research that led to the development of PDP was done in the 1970s, but PDP became popular in the 1980s with the release of the books *Parallel Distributed Processing: Explorations in the Microstructure of Cognition - Volume 1 (foundations)* and *Volume 2 (Psychological and Biological Models)*, by James L. McClelland, David E.

Rumelhart and the PDP Research Group. The books are now considered seminal connectionist works, and it is now common to fully equate PDP and connectionism, although the term "connectionism" is not used in the books.

Earlier work

PDP's direct roots were the perceptron theories of researchers such as Frank Rosenblatt from the 1950s and 1960s. But perceptron models were made very unpopular by the book *Perceptrons* by Marvin Minsky and Seymour Papert, published in 1969. It demonstrated the limits on the sorts of functions that single-layered perceptrons can calculate, showing that even simple functions like the exclusive disjunction could not be handled properly. The PDP books overcame this limitation by showing that multi-level, non-linear neural networks were far more robust and could be used for a vast array of functions.

Many earlier researchers advocated connectionist style models, for example in the 1940s and 1950s, Warren McCulloch, Walter Pitts, Donald Olding Hebb, and Karl Lashley. McCulloch and Pitts showed how neural systems could implement first-order logic: Their classic paper "A Logical Calculus of Ideas Immanent in Nervous Activity" (1943) is important in this development here. They were influenced by the important work of Nicolas Rashevsky in the 1930s. Hebb contributed greatly to speculations about neural functioning, and proposed a learning principle, Hebbian learning, that is still used today. Lashley argued for distributed representations as a result of his failure to find anything like a localized engram in years of lesion experiments.

Connectionism apart from PDP

Though PDP is the dominant form of connectionism, other theoretical work should also be classified as connectionist.

Many connectionist principles can be traced to early work in psychology, such as that of William James. Psychological theories based on knowledge about the human brain were fashionable in the late 19th century. As early as 1869, the neurologist John Hughlings Jackson argued for multi-level, distributed systems. Following from this lead, Herbert Spencer's *Principles of Psychology*, 3rd edition (1872), and Sigmund Freud's *Project for a Scientific Psychology* (composed 1895) propounded connectionist or proto-connectionist theories. These tended to be speculative theories. But by the early 20th century, Edward Thorndike was experimenting on learning that posited a connectionist type network.

In the 1950s, Friedrich Hayek proposed that spontaneous order in the brain arose out of decentralized networks of simple units. Hayek's work was rarely cited in the PDP literature until recently.

Another form of connectionist model was the relational network framework developed by the linguist Sydney Lamb in the 1960s. Relational networks have been only used by linguists, and were never unified with the PDP approach. As a result, they are now used by very few researchers.

There are also hybrid connectionist models, mostly mixing symbolic representations with neural network models. The hybrid approach has been advocated by some researchers (such as Ron Sun).

Connectionism vs. computationalism debate

As connectionism became increasingly popular in the late 1980s, there was a reaction to it by some researchers, including Jerry Fodor, Steven Pinker and others. They argued that connectionism, as it was being developed, was in danger of obliterating what they saw as the progress being made in the fields of cognitive science and psychology by the classical approach of computationalism. Computationalism is a specific form of cognitivism that argues that mental activity is computational, that is, that the mind operates by performing purely formal operations on symbols, like a Turing machine. Some researchers argued that the trend in connectionism was a reversion toward associationism and the abandonment of the idea of a language of thought, something they felt was mistaken. In contrast, it was those very tendencies that made connectionism attractive for other researchers.

Connectionism and computationalism need not be at odds, but the debate in the late 1980s and early 1990s led to opposition between the two approaches. Throughout the debate, some researchers have argued that connectionism and computationalism are fully compatible, though full consensus on this issue has not been reached. The differences between the two approaches that are usually cited are the following:

- Computationalists posit symbolic models that do not resemble underlying brain structure at all, whereas connectionists engage in "low-level" modeling, trying to ensure that their models resemble neurological structures.
- Computationalists in general focus on the structure of explicit symbols (mental models) and syntactical rules for their internal manipulation, whereas connectionists focus on learning from environmental stimuli and storing this information in a form of connections between neurons.
- Computationalists believe that internal mental activity consists of manipulation of explicit symbols, whereas connectionists believe that the manipulation of explicit symbols is a poor model of mental activity.
- Computationalists often posit domain specific symbolic sub-systems designed to support learning in specific areas of cognition (e.g., language, intentionality, number), whereas connectionists posit one or a small set of very general learning mechanisms.

But, despite these differences, some theorists have proposed that the connectionist architecture is simply the manner in which the symbol manipulation system happens to be implemented in the organic brain. This is logically possible, as it is well known that connectionist models can implement symbol manipulation systems of the kind used in computationalist models, as indeed they must be able if they are to explain the human ability to perform symbol manipulation tasks. But the debate rests on whether this symbol manipulation forms the foundation of cognition in general, so this is not a potential vindication of computationalism. Nonetheless, computational descriptions may be helpful high-level descriptions of cognition of logic, for example.

The debate largely centred on logical arguments about whether connectionist networks were capable of producing the syntactic structure observed in this sort of reasoning. This was later achieved, although using processes unlikely to be possible in the brain, thus the debate persisted. Today, progress in neurophysiology, and general advances in the understanding of neural networks, has led to the successful modelling of a great many of these early problems, and the debate about fundamental cognition has, thus, largely been decided among neuroscientists in favour of connectionism. However, these fairly recent developments have yet to reach consensus acceptance among those working in other fields, such as psychology or philosophy of mind.

Part of the appeal of computational descriptions is that they are relatively easy to interpret, and thus may be seen as contributing to our understanding of particular mental processes, whereas connectionist models are in general more opaque, to the extent that they may be describable only in very general terms (such as specifying the learning algorithm, the number of units, etc.), or in unhelpfully low-level terms. In this sense connectionist models may instantiate, and thereby provide evidence for, a broad theory of cognition (i.e., connectionism), without representing a helpful theory of the particular process that is being modelled. In this sense the debate might be considered as to some extent reflecting a mere difference in the level of analysis in which particular theories are framed.

The recent popularity of dynamical systems in philosophy of mind have added a new perspective on the debate; some authors now argue that any split between connectionism and computationalism is more conclusively characterized as a split between computationalism and dynamical systems.

The recently proposed Hierarchical temporal memory model may help resolving this dispute, at least to some degree, given that it explains how the neocortex extracts high-level (symbolic) information from low-level sensory input.

Notes

References

- Rumelhart, D.E., J.L. McClelland and the PDP Research Group (1986). *Parallel Distributed Processing: Explorations in the Microstructure of Cognition. Volume 1: Foundations*, Cambridge, MA: MIT Press
- McClelland, J.L., D.E. Rumelhart and the PDP Research Group (1986). *Parallel Distributed Processing: Explorations in the Microstructure of Cognition. Volume 2: Psychological and Biological Models*, Cambridge, MA: MIT Press
- Pinker, Steven and Mehler, Jacques (1988). *Connections and Symbols*, Cambridge MA: MIT Press.
- Jeffrey L. Elman, Elizabeth A. Bates, Mark H. Johnson, Annette Karmiloff-Smith, Domenico Parisi, Kim Plunkett (1996). *Rethinking Innateness: A connectionist perspective on development*, Cambridge MA: MIT Press.
- Marcus, Gary F. (2001). *The Algebraic Mind: Integrating Connectionism and Cognitive Science (Learning, Development, and Conceptual Change)*, Cambridge, MA: MIT Press

External links

- Dictionary of Philosophy of Mind entry on connectionism (http://philosophy.uwaterloo.ca/MindDict/connectionism.html)
- **Connectionism** (http://plato.stanford.edu/entries/connectionism) entry by James Garson in the ***Stanford Encyclopedia of Philosophy***
- A demonstration of Interactive Activation and Competition Networks (http://srsc.ulb.ac.be/pdp/iac/IAC.html)

Mind uploading

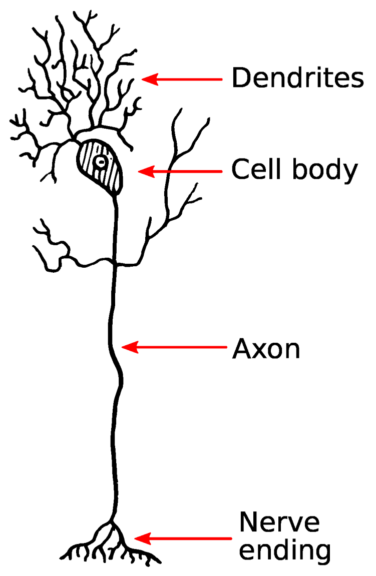
Whole brain emulation or **mind uploading** (sometimes called **mind transfer**) is the hypothetical process of transferring or copying a conscious mind from a brain to a non-biological substrate by scanning and mapping a biological brain in detail and copying its state into a computer system or another computational device. The computer would have to run a simulation model so faithful to the original that it would behave in essentially the same way as the original brain, or for all practical purposes, indistinguishably.[1] The simulated mind is assumed to be part of a virtual reality simulated world, supported by an anatomic 3D body simulation model. Alternatively, the simulated mind could be assumed to reside in a computer inside (or connected to) a humanoid robot or a biological body, replacing its brain.

Whole brain emulation is discussed by futurists as a "logical endpoint"[1] of the topical computational neuroscience and neuroinformatics fields, both about brain simulation for medical research purposes. It is discussed in artificial intelligence research publications[2] as an approach to strong AI. Among futurists and within the transhumanist movement it is an important proposed life extension technology, originally suggested in biomedical literature in 1971.[3] It is a central conceptual feature of numerous science fiction novels and films.

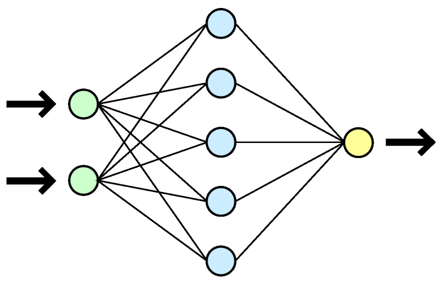
Whole brain emulation is considered by some scientists as a theoretical and futuristic but possible technology,[1] although mainstream research funders and scientific journals remain skeptical. Several contradictory predictions have been made about when a whole human brain can be emulated; some of the predicted dates have already passed. Substantial mainstream research and development are however being done in relevant areas including development of faster super computers, virtual reality, brain-computer interfaces, animal brain mapping and simulation, connectomics and information extraction from dynamically functioning brains.[4]

The question whether an emulated brain can be a human mind is debated by philosophers.

Overview



Neuron anatomical model


Simple artificial neural network

The human brain contains about 100 billion nerve cells called neurons, each individually linked to other neurons by way of connectors called axons and dendrites. Signals at the junctures (synapses) of these connections are transmitted by the release and detection of chemicals known as neurotransmitters. The established neuroscientific consensus is that the human mind is largely an emergent property of the information processing of this neural network.

Importantly, neuroscientists have stated that important functions performed by the mind, such as learning, memory, and consciousness, are due to purely physical and electrochemical processes in the brain and are governed by applicable laws. For example, Christof Koch and Giulio Tononi wrote in IEEE Spectrum:

> "Consciousness is part of the natural world. It depends, we believe, only on mathematics and logic and on the imperfectly known laws of physics, chemistry, and biology; it does not arise from some magical or otherworldly quality."[5]

The concept of mind uploading is based on this mechanistic view of the mind, and denies the vitalist view of human life and consciousness.

Eminent computer scientists and neuroscientists have predicted that computers will be capable of thought and even attain consciousness, including Koch and Tononi,[5] Douglas Hofstadter,[6] Jeff Hawkins,[6] Marvin Minsky,[7] Randal A. Koene,[8] and Rodolfo Llinas.[9]

Such a machine intelligence capability might provide a computational substrate necessary for uploading.

However, even though uploading is dependent upon such a general capability it is conceptually distinct from general forms of AI in that it results from dynamic reanimation of information derived from a specific human mind so that the mind retains a sense of historical identity (other forms are possible but would compromise or eliminate the life-extension feature generally associated with uploading). The transferred and reanimated information would become a form of artificial intelligence, sometimes called an infomorph or "*noömorph.*"

Many theorists have presented models of the brain and have established a range of estimates of the amount of computing power needed for partial and complete simulations. Using these models, some have estimated that uploading may become possible within decades if trends such as Moore's Law continue.[10]

Theoretical benefits

Immortality/backup

In theory, if the information and processes of the mind can be disassociated from the biological body, they are no longer tied to the individual limits and lifespan of that body. Furthermore, information within a brain could be partly or wholly copied or transferred to one or more other substrates (including digital storage or another brain), thereby reducing or eliminating mortality risk. This general proposal appears to have been first made in the biomedical literature in 1971 by biogerontologist George M. Martin of the University of Washington.[3]

Speedup

A computer-based intelligence such as an upload could potentially think much faster than a human even if it were no more intelligent. Human neurons exchange electrochemical signals with a maximum speed of about 150 meters per second, whereas the speed of light is about 300 million meters per second, about two million times faster. Also, neurons can generate a maximum of about 200 to 1000 action potentials or "spikes" per second, whereas the number of signals per second in modern computer chips is about 3 GHz (about two million times greater) and expected to increase by at least a factor 100. Therefore, even if the computer components responsible for simulating a brain were not significantly smaller than a biological brain, and even if the temperature of these components was not significantly lower, Eliezer Yudkowsky of the Singularity Institute for Artificial Intelligence calculates a theoretical upper bound for the speed of a future artificial neural network. It could in theory run about 1 million times faster than a real brain, experiencing about a year of subjective time in only 31 seconds of real time.[11][12][13]

However, such a massively parallel implementation would require separate computational units for each of the hundred billion neurons and each of the hundred trillion synapses. That requires an enormously large computer or artificial neural network in comparison with today's super-computers.[12] In a less futuristic implementation, time-sharing would allow several neurons to be emulated sequentially by the same computational unit. Thus the size of the computer would be restricted, but the speedup would be lower. Assuming that cortical minicolumns organized into hypercolumns are the computational units, mammal brains can be emulated by today's super computers, but with slower speed than in a biological brain.[14]

Space travel

Mind uploading poses potential benefits for interstellar space travel because it would allow immortal beings to travel the cosmos without suffering from extreme acceleration. A whole society of uploads can be emulated by a computer on a very small spaceship, similar to a space probe, that would consume much less fuel and may accelerate much more than space travels for biological humans. The uploads would have control of the ship and would be able to make decisions about the crafts voyage in real time, independent of signals from Earth, that might eventually take months or years to reach the craft as it journeys out into the cosmos. Because a virtual conscious can be set into a state of hibernation, or slowed down, the virtual minds need not experience the boredom of hundreds if not thousands of years of travel. Instead they would only awake when on board computers detected that the craft had arrived at its destination. In the book Omega point (1994), the author suggests that the universe eventually would be colonized by such machine intelligence, which ultimately would try to turn all matter in the universe into energy and computational power.

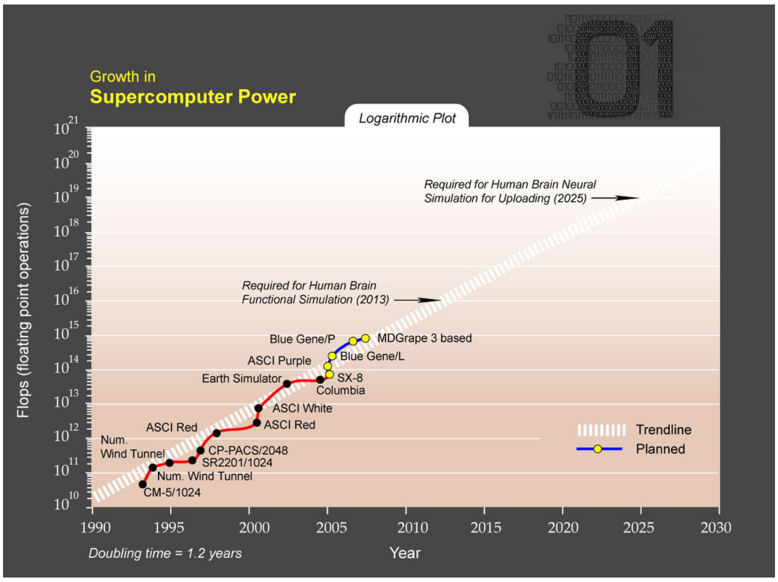
Another possibility for travel would be wireless transmission of a person's brain model between computers on already inhabited locations. Such travel would require only the energy to transmit enough powerful signals suffently long time so that they reach the target destination. The travelling time would be a sum of the wave propagation delay (depending on the distance) and the data transmission delay (depending on the possible bit rate, which depends on the distance and transmission power); both could constitute several years for inter-stellar travelling. The travelers experienced time from transmitter to receiver would be instantaneous.

Multiple/parallel existence

Another concept explored in science fiction is the idea of more than one running "copy" of a human mind existing at once. Such copies could potentially allow an "individual" to experience many things at once, and later integrate the experiences of all copies into a central mentality at some point in the future, effectively allowing a single sentient being to "be many places at once" and "do many things at once"; this concept has been explored in fiction. Such partial and complete copies of a sentient being raise interesting questions regarding identity and individuality.

Relevant technologies and techniques

Computational capacity



Futurist Ray Kurzweil's projected supercomputer processing power based on Moore's law exponential development of computing capacity. Here the computational capacity doubling time is assumed to be 1.2 years.

Advocates of mind uploading point to Moore's law to support the notion that the necessary computing power is expected to become available within a few decades. However, the actual computational requirements for running an uploaded human mind are very difficult to quantify, potentially rendering such an argument specious.

Regardless of the techniques used to capture or recreate the function of a human mind, the processing demands are likely to be immense, due to the large number of neurons in the human brain along with the considerable complexity of each neuron.

In 2004, Henry Markram, lead researcher of the "Blue Brain Project", has stated that "it is not [their] goal to build an intelligent neural network", based solely on the computational demands such a project would have.[15]

> It will be very difficult because, in the brain, every molecule is a powerful computer and we would need to simulate the structure and function of trillions upon trillions of molecules as well as all the rules that govern how they interact. You would literally need computers that are trillions of times bigger and faster than anything existing today.[16]

Five years later, after successful simulation of part of a rat brain, the same scientist was much more bold and optimistic. In 2009, when he was director of the Blue Brain Project, he claimed that

> A detailed, functional artificial human brain can be built within the next 10 years [17]

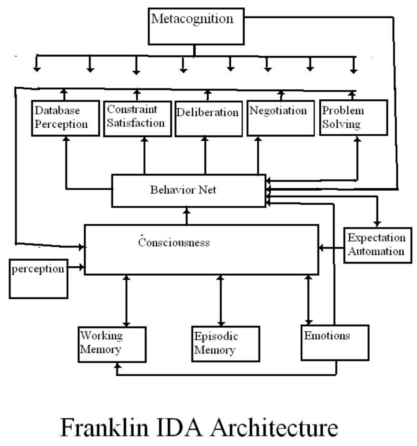
Required computational capacity strongly depend on the chosen level of simulation model scale[1]:

Level	CPU demand (FLOPS)	Memory demand (Tb)	$1 million super-computer (Earliest year of making)
Analog network population model	10^{15}	10^{2}	2008
Spiking neural network	10^{18}	10^{4}	2019
Electrophysiology	10^{22}	10^{4}	2033
Metabolome	10^{25}	10^{6}	2044
Proteome	10^{26}	10^{7}	2048
States of protein complexes	10^{27}	10^{8}	2052
Distribution of complexes	10^{30}	10^{9}	2063

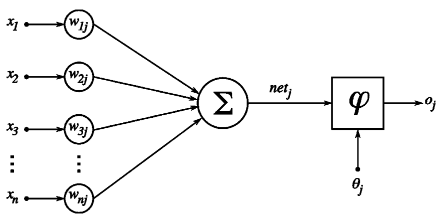
Stochastic behavior of single molecules	10^{43}	10^{14}	2111

|+ align="bottom" |Estimates from *Sandberg, Bostrom, 2008*

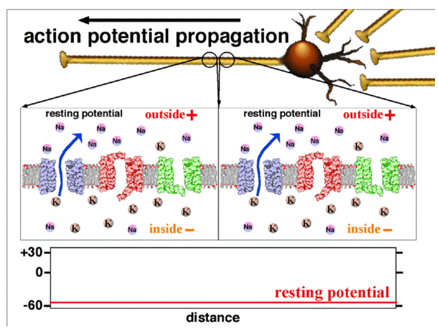
Simulation model scale



A high-level cognitive AI model of the brain architecture is not required for brain emulation



Simple neuron model: Black-box dynamic non-linear signal processing system



Metabolism model: The movement of positively-charged ions through the ion channels controls the membrane electrical action potential in an axon.

Since the function of the human mind, and how it might arise from the working of the brain's neural network, are poorly understood issues, mind uploading relies on the idea of neural network emulation. Rather than having to understand the high-level psychological processes and large-scale structures of the brain, and model them using classical artificial intelligence methods and cognitive psychology models, the low-level structure of the underlying neural network is captured, mapped and emulated with a computer system. In computer science terminology, rather than analyzing and reverse engineering the behavior of the algorithms and data structures that resides in the brain, a blueprint of its source code is translated to another programming language. The human mind and the personal identity then, theoretically, is generated by the emulated neural network in an identical fashion to it being generated by the biological neural network.

On the other hand, a molecule-scale simulation of the brain is not expected to be required, provided that the functioning of the neurons is not affected by quantum mechanical processes. The neural network emulation approach only requires that the functioning and interaction of neurons and synapses are understood. It is expected that it is sufficient with a black-box signal processing model of how the neurons respond to nerve impulses (electrical as well as chemical synaptic transmission).

A sufficiently complex and accurate model of the neurons is required. A traditional artificial neural network model, for example multi-layer perceptron network model, is not considered as sufficient. A dynamic spiking neural network model is required, which reflects that the neuron fires only when a membrane potential reaches a certain level. It is likely that the model must include delays, non-linear functions and differential equations describing the relation between electrophysical parameters such as electrical currents, voltages, membrane states (ion channel states) and neuromodulators.

Since learning and long-term memory are believed to result from strengthening or weakening the synapses via a mechanism known as synaptic plasticity or synaptic adaptation, the model should include this mechanism. The response of sensory receptors to various stimuli must also be modeled.

Furthermore, the model may have to include metabolism, i.e. how the neurons are affected by hormones and other chemical substances that

may cross the blood–brain barrier. It is considered likely that the model must include currently unknown neuromodulators, neurotransmitters and ion channels. It is considered unlikely that the simulation model has to include protein interaction, which would make it computationally complex.[1]

A digital computer simulation model of an analog system such as the brain is an approximation that introduces random quantization errors and distortion. However, the biological neurons also suffer from randomness and limited precision, for example due to background noise. The errors of the discrete model can be made smaller than the randomness of the biological brain by choosing a sufficiently high variable resolution and sample rate, and sufficiently accurate models of non-linearities. The computational power and computer memory must however be sufficient to run such large simulations, preferably in real time.

Scanning and mapping scale of an individual

When modelling and simulating the brain of a specific individual, a brain map or connectivity database showing the connections between the neurons must be extracted from an anatomic model of the brain. For whole brain simulation, this network map should show the connectivity of the whole nervous system, including the spinal cord, sensory receptors, and muscle cells. Destructive scanning of a small sample of tissue from a mouse brain including synaptic details is possible as of 2010.[18]

However, if short-term memory and working memory include prolonged or repeated firing of neurons, as well as intra-neural dynamic processes, the electrical and chemical signal state of the synapses and neurons may be hard to extract. The uploaded mind may then perceive a memory loss of the events and mental processes immediately before the time of brain scanning.[1]

A full brain map has been estimated to occupy less than 2 x 10^{16} bytes (20,000 TB) and would store the addresses of the connected neurons, the synapse type and the synapse "weight" for each of the brains' 10^{15} synapses.[1] However, the biological complexities of true brain function (e.g. the epigenetic states of neurons, protein components with multiple functional states, etc.) may preclude an accurate prediction of the volume of binary data required to faithfully represent a functioning human mind.

Serial sectioning

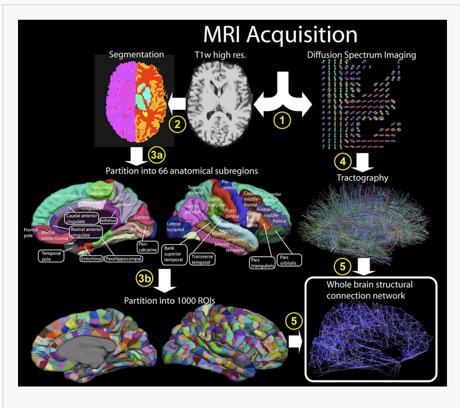
A possible method for mind uploading is serial sectioning, in which the brain tissue and perhaps other parts of the nervous system are frozen and then scanned and analyzed layer by layer, which for frozen samples at nano-scale requires a cryo-ultramicrotome, thus capturing the structure of the neurons and their interconnections.[19] The exposed surface of frozen nerve tissue would be scanned and recorded, and then the surface layer of tissue removed. While this would be a very slow and labor intensive process, research is currently underway to automate the collection and microscopy of serial sections.[20] The scans would then be analyzed, and a model of the neural net recreated in the system that the mind was being uploaded into.

Serial sectioning of a brain

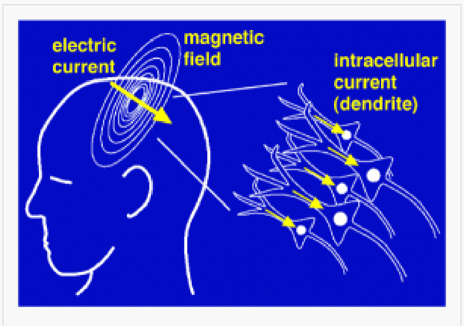
There are uncertainties with this approach using current microscopy techniques. If it is possible to replicate neuron function from its visible structure alone, then the resolution afforded by a scanning electron microscope would suffice for such a technique.[20] However, as the function of brain tissue is partially determined by molecular events (particularly at synapses, but also at other places on the neuron's cell membrane), this may not suffice for capturing and simulating neuron functions. It may be possible to extend the techniques of serial sectioning and to capture the internal molecular makeup of neurons, through the use of sophisticated immunohistochemistry

staining methods that could then be read via confocal laser scanning microscopy. However, as the physiological genesis of 'mind' is not currently known, this method may not be able to access all of the necessary biochemical information to recreate a human brain with sufficient fidelity.

Brain imaging



Process from MRI acquisition to whole brain structural network[21]



Magnetoencephalography

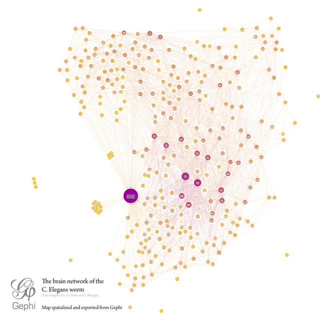
It may also be possible to create functional 3D maps of the brain activity, using advanced neuroimaging technology, such as functional MRI (fMRI, for mapping change in blood flow), Magnetoencephalography (MEG, for mapping of electrical currents), or combinations of multiple methods, to build a detailed three-dimensional model of the brain using non-invasive and non-destructive methods. Today, fMRI is often combined with MEG for creating functional maps of human cortex during more complex cognitive tasks, as the methods complement each other. Even though current imaging technology lacks the spatial resolution needed to gather the information needed for such a scan, important recent and future developments are predicted to substantially improve both spatial and temporal resolutions of existing technologies.[22]

Current research

Several animal brains have been mapped and at least partly simulated.

Simulation of C. elegans roundworm neural system

The connectivity of the neural circuit for touch sensitivity of the simple C. elegans nematode (roundworm) was mapped in 1985,[23] and partly simulated in 1993.[24] Several software simulation models of the complete neural and muscular system, and to some extent the worm's physical environment, have been presented since 2004, and are in some cases available for downloading.[25] However, we still lack understanding of how the neurons and the connections between them generate the surprisingly complex range of behaviors that are observed in this relatively simple organism.[26][27]



Brain map of the C. elegans roundworm 302 neurons, interconnected by 5000 synapses.

Simulation of Drosophila fruit fly neural system

The brain belonging to the fruit fly Drosophila is also thoroughly studied, and to some extent simulated.[28]

Mouse brain simulation

An artificial neural network described as being "as big and as complex as half of a mouse brain" was run on an IBM blue gene supercomputer by a University of Nevada research team in 2007. A simulated time of one second took ten seconds of computer time. The researchers said they had seen "biologically consistent" nerve impulses flowed through the virtual cortex. However, the simulation lacked the structures seen in real mice brains, and they intend to improve the accuracy of the neuron model.[29]

Blue Brain is a project, launched in May 2005 by IBM and the Swiss Federal Institute of Technology in Lausanne, with the aim to create a computer simulation of a mammalian cortical column, down to the molecular level.[30] The project uses a supercomputer based on IBM's Blue Gene design to simulate the electrical behavior of neurons based upon their synaptic connectivity and complement of intrinsic membrane currents. The initial goal of the project, completed in December 2006,[31] was the simulation of a rat neocortical column, which can be considered the smallest functional unit of the neocortex (the part of the brain thought to be responsible for higher functions such as conscious thought), containing 10,000 neurons (and 10^8 synapses). Between 1995 and 2005, Henry Markram mapped the types of neurons and their connections in such a column. In November 2007,[32] the project reported the end of the first phase, delivering a data-driven process for creating, validating, and researching the neocortical column. The project seeks to eventually reveal aspects of human cognition and various psychiatric disorders caused by malfunctioning neurons, such as autism, and to understand how pharmacological agents affect network behavior.

An organization called the Brain Preservation Foundation [33] was founded in 2010 and is offering a Brain Preservation Technology prize to promote exploration of brain preservation technology in service of humanity. The Prize, currently $106,000, will be awarded in two parts, 25% to the first international team to preserve a whole mouse brain, and 75% to the first team to preserve a whole large animal brain in a manner that could also be adopted for humans in a hospital or hospice setting immediately upon clinical death. Ultimately the goal of this prize is to generate a whole brain map which may be used in support of separate efforts to upload and possibly 'reboot' a mind in virtual space.

Issues

Legal, ethical, political and economical issues

If simulated worlds would come true, it may be difficult to ensure the protection of human rights. For example, social science researchers might be tempted to secretly expose simulated minds, or whole isolated societies of simulated minds, to controlled experiments in which many copies of the same minds are exposed (serially or simultaneously) to different test conditions.

The only limited physical resource to be expected in a simulated world is the computational capacity, and thus the speed and complexity of the simulation. Wealthy or privileged individuals in a society of uploads might thus experience more subjective time than others in the same real time, or may be able to run multiple copies of themselves or others, and thus produce more service and become even more wealthy. Others may suffer from computational resource starvation and show a slow motion behavior.

Copying vs. moving

Another philosophical issue with mind uploading is whether an uploaded mind is really the "same" sentience, or simply an exact copy with the same memories and personality; or, indeed, what the difference could be between such a copy and the original (see the Swampman thought experiment). This issue is especially complex if the original remains essentially unchanged by the procedure, thereby resulting in an obvious copy which could potentially have rights separate from the unaltered, obvious original.

Most projected brain scanning technologies, such as serial sectioning of the brain, would necessarily be destructive, and the original brain would not survive the brain scanning procedure. But if it can be kept intact, the computer-based consciousness could be a copy of the still-living biological person. It is in that case implicit that copying a consciousness could be as feasible as literally moving it into one or several copies, since these technologies generally involve simulation of a human brain in a computer of some sort, and digital files such as computer programs can be copied precisely. It is usually assumed that once the versions are exposed to different sensory inputs, their experiences would begin to diverge, but all their memories up until the moment of the copying would remain the same.

The problem is made even more serious by the possibility of creating a potentially infinite number of initially identical copies of the original person, which would of course all exist simultaneously as distinct beings. The most parsimonious view of this phenomenon is that the two (or more) minds would share memories of their past but from the point of duplication would simply be distinct minds (although this is complicated by merging). Many complex variations are possible.

Depending on computational capacity, the simulation may run at faster or slower simulation time as compared to the elapsed physical time, resulting in that the simulated mind would perceive that the physical world is running in slow motion or fast motion respectively, while biological persons will see the simulated mind in fast or slow motion respectively.

A brain simulation can be started, paused, backed-up and rerun from a saved backup state at any time. The simulated mind would in the latter case forget everything that has happened after the instant of backup, and perhaps not even be aware that it is repeating itself. An older version of a simulated mind may meet a younger version and share experiences with it.

Bekenstein bound

The Bekenstein bound is an upper limit on information that can be contained within a given finite region of space which has a finite amount of energy or, conversely, the maximum amount of information required to perfectly describe a given physical system down to the quantum level.[34]

An average human brain has a weight of 1.5 kg and a volume of 1260 cm^3. The energy ($E = m \cdot c^2$) will be $1.34813 \cdot 10^{17}$ J and if the brain is approximate to a sphere then the radius ($V = 4 \cdot \pi \cdot r^3/3$) will be $6.70030 \cdot 10^{-2}$ m.

The Bekenstein bound ($I \leq 2 \cdot \pi \cdot r \cdot E \hbar \cdot c \cdot \ln 2$) for an average human brain would be $2.58991 \cdot 10^{42}$ bit and represents an upper bound on the information needed to perfectly recreate the average human brain down to the quantum level. This implies that the number of different states ($\Omega = 2^I$) of the human brain (and of the mind if the physicalism is true) is at most $10^{7.79640 \cdot 10}41$.

However, as described above, many mind uploading advocates expect that quantum-level models and molecule-scale simulation of the neurons will not be needed, so the Bekenstein bound only represents a maximum upper limit. The hippocampus of a human adult brain has been estimated to store a limit of up to 2.5 petabyte of binary data equivalent.[35]

Mind uploading advocates

Mind uploading is also advocated by a number of researchers in neuroscience and artificial intelligence, such as Marvin Minsky. In 1993, Joe Strout created a small web site called the Mind Uploading Home Page, and began advocating the idea in cryonics circles and elsewhere on the net. That site has not been actively updated in recent years, but it has spawned other sites including MindUploading.org, run by Randal A. Koene, Ph.D., who also moderates a mailing list on the topic. These advocates see mind uploading as a medical procedure which could eventually save countless lives.

Many transhumanists look forward to the development and deployment of mind uploading technology, with transhumanists such as Nick Bostrom predicting that it will become possible within the 21st century due to technological trends such as Moore's Law.[1]

The book *Beyond Humanity: CyberEvolution and Future Minds* by Gregory S. Paul & Earl D. Cox, is about the eventual (and, to the authors, almost inevitable) evolution of computers into sentient beings, but also deals with human mind transfer. Richard Doyle's *Wetwares: Experiments in PostVital Living* deals extensively with uploading from the perspective of distributed embodiment, arguing for example that humans are currently part of the "artificial life phenotype." Doyle's vision reverses the polarity on uploading, with artificial life forms such as uploads actively seeking out biological embodiment as part of their reproductive strategy. Raymond Kurzweil, a prominent advocate of transhumanism and the likelihood of a technological singularity, has suggested that the easiest path to human-level artificial intelligence may lie in "reverse-engineering the human brain", which he usually uses to refer to the creation of a new intelligence based on the general "principles of operation" of the brain, but he also sometimes uses the term to refer to the notion of uploading individual human minds based on highly detailed scans and simulations. This idea is discussed on pp. 198–203 of his book *The Singularity is Near*, for example.

References

[1] Anders, Sandberg; Nick <script>, Boström (2008). *Whole Brain Emulation: A Roadmap* (http://www.fhi.ox.ac.uk/Reports/2008-3.pdf). Technical Report #2008-3. Future of Humanity Institute, Oxford University. . Retrieved 5 April 2009. "*The basic idea is to take a particular brain, scan its structure in detail, and construct a software model of it that is so faithful to the original that, when run on appropriate hardware, it will behave in essentially the same way as the original brain.*"

[2] Goertzel, Ben (Dec 2007). "Human-level artificial general intelligence and the possibility of a technological singularity: a reaction to Ray Kurzweil's The Singularity Is Near, and McDermott's critique of Kurzweil" (http://scholar.google.com/scholar?hl=sv&lr=&cluster=15189798216526465792). *Artificial Intelligence* **171** (18, Special Review Issue): 1161–1173. doi:10.1016/j.artint.2007.10.011. . Retrieved 1 April 2009.

[3] Martin GM (1971). "Brief proposal on immortality: an interim solution". *Perspectives in Biology and Medicine* **14** (2): 339. PMID 5546258.

[4] Kay KN, Naselaris T, Prenger RJ, Gallant JL (March 2008). "Identifying natural images from human brain activity". *Nature* **452** (7185): 352–5. Bibcode 2008Natur.452..352K. doi:10.1038/nature06713. PMID 18322462.

[5] Koch, Christof; Tononi, Giulio (2008). "Can machines be conscious?". *IEEE Spectrum* **45**: 55. doi:10.1109/MSPEC.2008.4531463.

[6] IEEE Spectrum Special Report on the Singularity (http://www.spectrum.ieee.org/jun08/6277)

[7] Marvin Minsky, Conscious Machines, in 'Machinery of Consciousness', Proceedings, National Research Council of Canada, 75th Anniversary Symposium on Science in Society, June 1991.

[8] MindUploading.org (http://minduploading.org)

[9] Llinas, R (2001). *I of the Vortex: From Neurons to Self*. Cambridge: MIT Press. pp. 261–262. ISBN 0-262-62163-0.

[10] Ray Kurzweil, Live Forever–Uploading The Human Brain…Closer Than You Think (http://www.kurzweilai.net/articles/art0157.html?printable=1), Psychology Today, February 2000.

[11] Eliezer Yudkowsky, Artificial Intelligence as a Positive and Negative Factor in Global Risk (http://spkurdyumov.narod.ru/Bostrom20.htm) Technical report 2006, later book chapter.

[12] What is singularity? (http://singinst.org/overview/whatisthesingularity), web page by The Singularity Institute

[13] http://singinst.org/upload/singularitysummit.ppt

[14] Johansson C and Lansner A., *Towards cortex sized artificial neural systems*. Neural Networks, 20: 48-61, 2007

[15] Blue Brain Project (http://bluebrainproject.epfl.ch/FAQs.htm)

[16] Blue Brain Project FAQ (http://bluebrain.epfl.ch/page18924.html), 2004

[17] BBC News, Artificial brain '10 years away' (http://news.bbc.co.uk/2/hi/8164060.stm)

[18] "New imaging method developed at Stanford reveals stunning details of brain connections" (http://www.medicaldaily.com/news/20301117/3877/new-imaging-method-developed-at-stanford-reveals-stunning-details-of-brain-connections.htm). Medical Daily. .

[19] Merkle, R., 1989, Large scale analysis of neural structures (http://www.merkle.com/merkleDir/brainAnalysis.html), CSL-89-10 November 1989, [P89-00173]

[20] ATLUM Project (http://www.mcb.harvard.edu/lichtman/ATLUM/ATLUM_web.htm)

[21] Hagmann, Patric; Cammoun, Leila; Gigandet, Xavier; Meuli, Reto; Honey, Christopher J.; Wedeen, Van J.; Sporns, Olaf; Friston, Karl J. (2008). Friston, Karl J.. ed. "Mapping the Structural Core of Human Cerebral Cortex". *PLoS Biology* **6** (7): e159. doi:10.1371/journal.pbio.0060159. PMC 2443193. PMID 18597554.

[22] Glover, Paul; Bowtell, Richard (2009). "Medical imaging: MRI rides the wave". *Nature* **457** (7232): 971–2. Bibcode 2009Natur.457..971G. doi:10.1038/457971a. PMID 19225512.

[23] Chalfie, M., Sulston, J. E., White, J. G., Southgate, E., Thomson, J. N., and Brenner, S. (1985). The neural circuit for touch sensitivity in Caenorhabditis elegans (http://www.jneurosci.org/content/5/4/956.full.pdf). The Journal of Neuroscience, 5(4):956–96.

[24] Niebur, E. and Erdos, P. (1993). Theory of the locomotion of nematodes: Control of the somatic motor neurons by interneurons (http://www.ncbi.nlm.nih.gov/pubmed/8260760). Mathematical Biosciences, 118(1):51–82.

[25] Bryden, J. and Cohen, N. (2004). A simulation model of the locomotion controllers for the nematodode Caenorhabditis elegans. In Schaal, S., Ijspeert, A., Billard, A., Vijayakumar, S., Hallam, J., and Meyer, J.-A., editors, From Animals to Animats 8: Proceedings of the eighth international conference on the Simulation of Adaptive Behaviour, pages 183–192.

[26] Mark Wakabayashi (http://itee.uq.edu.au/~markw/celegans/), with links to MuCoW simulation software, a demo video and the doctoral thesis COMPUTATIONAL PLAUSIBILITY OF STRETCH RECEPTORS AS THE BASIS FOR MOTOR CONTROL IN C. elegans, 2006.

[27] (http://scholar.google.se/scholar?cluster=8784732820289974684&hl=sv&as_sdt=0&sciodt=0)

[28] Arena, P.; Patane, L.; Termini, P.S.; An insect brain computational model inspired by Drosophila melanogaster: Simulation results (http://scholar.google.se/scholar?cluster=12345296403665184996&hl=sv&as_sdt=0,5), The 2010 International Joint Conference on Neural Networks (IJCNN).

[29] bbc.co.uk BBC News, April 2007: Mouse brain simulated on computer (http://news.bbc.co.uk/1/hi/technology/6600965.stm)

[30] Herper, Matthew (June 6, 2005). "IBM Aims To Simulate A Brain" (http://www.forbes.com/technology/sciences/2005/06/06/cx_mh_0606ibm.html). Forbes. . Retrieved 2006-05-19.

[31] "Project Milestones" (http://bluebrain.epfl.ch/Jahia/site/bluebrain/op/edit/pid/19085). *Blue Brain*. . Retrieved 2008-08-11.

[32] "News and Media information" (http://bluebrain.epfl.ch/page18700.html). *Blue Brain*. . Retrieved 2008-08-11.

[33] http://www.brainpreservation.org

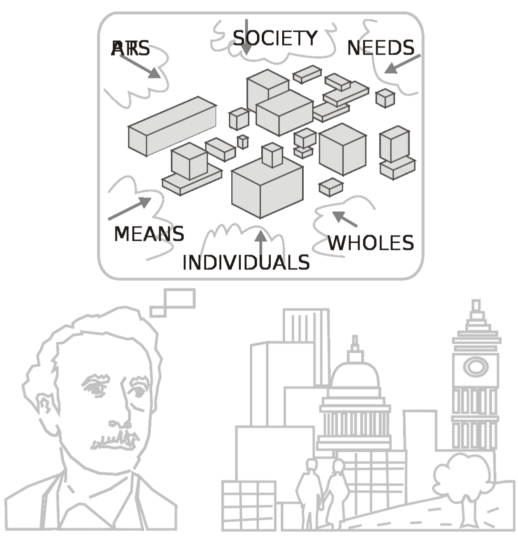
[34] J. D. Bekenstein, "Black Holes and the Second Law" (http://www.phys.huji.ac.il/~barak_kol/Courses/Black-holes/reading-papers/Beken-Entropy.pdf), *Lettere al Nuovo Cimento*, Vol. 4, No 15 (August 12, 1972), pp. 737-740, doi:10.1007/BF02757029, Bibcode: 1972NCimL...4..737B. Mirror link (http://www.webcitation.org/5pvpODjvK).
[35] Paul Reber, What Is the Memory Capacity of the Human Brain? (http://www.scientificamerican.com/article.cfm?id=what-is-the-memory-capacity), Scientific American, May 2010.

External links

- Blue Brain Project (http://bluebrain.epfl.ch/)
- Reverse Engineering The Brain (http://www.spectrum.ieee.org/print/6268) from IEEE Spectrum
- Reverse-engineer the brain (http://www.engineeringchallenges.org/cms/8996/9109.aspx) from National Academy of Engineering
- The Duplicates Paradox (http://www.benbest.com/philo/doubles.html) by Ben Best; theories about the problem of personal continuity
- Joe Strout's Mind Uploading Home Page (http://www.ibiblio.org/jstrout/uploading/)
- "The Day You Discard Your Body" (http://marshallbrain.com/discard1.htm) by Marshall Brain
- Winter of our Consciousness (http://futurefire.net/2005.03/nonfiction/consciousness.html), article in The Future Fire 3
- Reality 3.0: Uploading, Hypermediation & Paradise Engineering (http://www.enthea.org/writing/reality-3-0-hypermediation-paradise-engineering/) by Paul Hughes
- Transhumanist writings on uploading (http://www.foresight.org/Nanomedicine/Uploading.html) from the Foresight Institute
- Society of Neural Prosthetics and Whole Brain Emulation Science (http://www.minduploading.org/)
- Carboncopies (http://www.carboncopies.org/)

Systems science

Systems science is an interdisciplinary field that studies the nature of complex systems in nature, society, and science itself. It aims to develop interdisciplinary foundations that are applicable in a variety of areas, such as engineering, biology, medicine, and social sciences.



Impression of systems thinking about society[1]

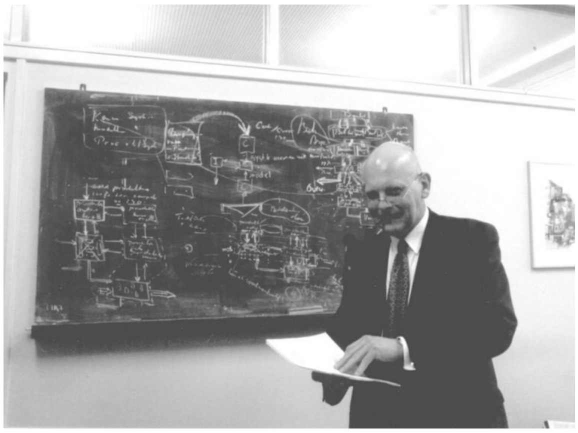
Systems science covers formal sciences such as complex systems, cybernetics, dynamical systems theory, and systems theory, and applications in the field of the natural and social sciences and engineering, such as control theory, operations research, social systems theory, systems biology, systems dynamics, systems ecology, systems engineering and systems psychology.

Theories

Since the emergence of the General Systems Research in the 1950s systems thinking and systems science have developed into many theoretical frameworks.

Systems analysis

Systems analysis is the branch of systems science that analyzes systems and the interactions within those systems, often prior to their automation as computer models. This field is closely related to operations research.


Systems notes of Henk Bikker, TU Delft, 1991

Systems design

In computing, systems design is the process or art of defining the hardware and software architecture, components, modules, interfaces, and data for a computer system to satisfy specified requirements. One could see it as the application of systems theory to computing. Some overlap with the discipline of systems analysis appears inevitable.

System dynamics

System dynamics is an approach to understanding the behaviour of complex systems over time. It deals with internal feedback loops and time delays that affect the behaviour of the entire system.[2] What makes using system dynamics different from other approaches to studying complex systems is the use of feedback loops and stocks and flows. These elements help describe how even seemingly simple systems display baffling nonlinearity.

Systems engineering

Systems engineering (SE) is an interdisciplinary field of engineering, that focuses on the development and organization of complex artificial systems. Systems engineering has emerged into all kinds of sciences, and universities nowadays offer all kinds of specialized academic programs.[3]

Systems Methodologies

There are several types of Systems Methodologies, that is, disciplines for analysis of systems. For example:

- Soft Systems Methodology (SSM) : in the field of organizational studies is an approach to organisational process modelling, and it can be used both for general problem solving and in the management of change. It was developed in England by academics at the University of Lancaster Systems Department through a ten-year Action Research programme.
- System Development Methodology (SDM) in the field of IT development is a general term applied to a variety of structured, organized processes for developing information technology and embedded software systems.
- Viable systems approach (vSa) is a methodology useful for the understanding and governance of complex phenomena; it has been successfully proposed in the field of management, decision making, marketing and service.

Systems theories

Systems theory is an interdisciplinary field that studies complex systems in nature, society, and science. More specifically, it is a conceptual framework by which one can analyze and/or describe any group of objects that work in concert to produce some result.

Systems science

Systems sciences are scientific disciplines partly based on systems thinking such as chaos theory, complex systems, control theory, cybernetics, sociotechnical systems theory, systems biology, systems ecology, systems psychology and the already mentioned systems dynamics, systems engineering, and systems theory.

Fields

Systems sciences cover formal sciences like dynamical systems theory and applications in the natural and social sciences and engineering, such as social systems theory and systems dynamics.

• Chaos theory	• Operations research	• Systems psychology • Ergonomics • Family systems theory • Systemic therapy
• Complex systems	• Systems biology • Computational systems biology • Synthetic biology • Systems immunology	• Systems theory • Biochemical systems theory • Ecological systems theory • Developmental systems theory • General systems theory • Living systems theory • LTI system theory • Sociotechnical systems theory • Mathematical system theory • World-systems theory
• Complex system	• System dynamics • Social dynamics	• Systems theory in sociology • Talcott Parsons • John N. Warfield • Niklas Luhmann
• Cybernetics • Biocybernetics • Engineering cybernetics • Management cybernetics • Medical cybernetics • New Cybernetics • Second-order cybernetics	• Systems ecology • Ecosystem ecology	
• Control theory • Affect control theory • Control engineering • Control systems • Dynamical systems • Perceptual control theory	• Systems engineering • Biological systems engineering • Earth systems engineering and management • Enterprise systems engineering • Systems analysis • Systems theory in anthropology	

Systems scientists

General systems scientists can be divided into different generations. The founders of the systems movement like Ludwig von Bertalanffy, Kenneth Boulding, Ralph Gerard, James Grier Miller, George J. Klir,and Anatol Rapoport were all born between 1900 and 1920. They all came from different natural and social science disciplines and joined forces in the 1950s to established the general systems theory paradigm. Along with the organization of their efforts a first generation of systems scientists rose.

Among them were other scientists like Ackoff, Ashby and Churchman, who popularized the systems concept in the 1950s and 1960s. These scientists inspired and educated a second generation with more notable scientist like Ervin Laszlo (1932) and Fritjof Capra (1939), who wrote about systems theory in the 1970s and 1980s. Others got acquainted and started studying these works in the 1980s and started writing about it since the 1990s. Debora Hammond can be seen as a typical representative of these third generation of general systems scientists.

Organizations

The International Society for the Systems Sciences (ISSS) is an organisation for interdisciplinary collaboration and synthesis of systems sciences. The ISSS is unique among systems-oriented institutions in terms of the breadth of its scope, bringing together scholars and practitioners from academic, business, government, and non-profit organizations. Based on fifty years of tremendous interdisciplinary research from the scientific study of complex systems to interactive approaches in management and community development. This society was initially conceived in 1954 at the Stanford Center for Advanced Study in the Behavioral Sciences by Ludwig von Bertalanffy, Kenneth Boulding, Ralph Gerard, and Anatol Rapoport.

In the field of systems science the International Federation for Systems Research (IFSR) is an international federation for global and local societies in the field of systems science. This federation is a non-profit, scientific and educational agency founded in 1981, and constituted of some thirty member organizations from various countries. The overall purpose of this Federation is to advance cybernetic and systems research and systems applications and to serve the international systems community.

The best known research institute in the field is the Santa Fe Institute (SFI) located in Santa Fe, New Mexico, United States, dedicated to the study of complex systems. This institute was founded in 1984 by George Cowan, David Pines, Stirling Colgate, Murray Gell-Mann, Nick Metropolis, Herb Anderson, Peter A. Carruthers, and Richard Slansky. All but Pines and Gell-Mann were scientists with Los Alamos National Laboratory. SFI's original mission was to disseminate the notion of a separate interdisciplinary research area, complexity theory referred to at SFI as complexity science.

In India, the Indian Institute of Technology Rajasthan has set up a center of excellence in Systems Science, offering a research as well as an academic platform for students at undergraduate, post graduate and doctoral levels.

References

[1] Illustration is made by Marcel Douwe Dekker (2007) based on an own standard and Pierre Malotaux (1985), "Constructieleer van de mensenlijke samenwerking", in BB5 Collegedictaat TU Delft, pp. 120-147.
[2] MIT System Dynamics in Education Project (SDEP) (http://sysdyn.clexchange.org)
[3] See for further details: List of systems engineering at universities

- (http://www.iitj.ac.in/SS.html)

Further reading

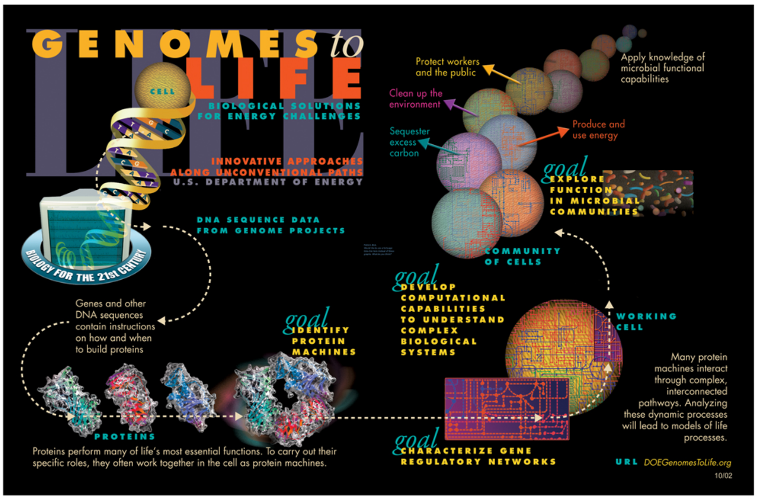
- B. A. Bayraktar, *Education in Systems Science*, 1979, 369 pp.
- Kenneth D. Bailey, "Fifty Years of Systems Science:Further Reflections", *Systems Research and Behavioral Science*, 22, 2005, pp. 355–361. doi:10.1002/sres.711
- Robert L. Flood, Ewart R Carson, *Dealing with Complexity: An Introduction to the Theory and Application of Systems Science*, 1988.
- George J. Klir, *Facets of Systems Science*, Plenum Press, 1991.
- Ervin László, *Systems Science and World Order: Selected Studies*, 1983.
- Anatol Rapoport (ed.), *General Systems: Yearbook of the Society for the Advancement of General Systems Theory*, Society for General Systems Research, Vol 1., 1956.
- Rugai, Nick, *Computational Epistemology: From Reality to Wisdom*, Book, Nitro Rigging LLC, ISBN 978-1-257-78505-6
- Li D. Xu, "The contributions of Systems Science to Information Systems Research", *Systems Research and Behavioral Science,* 17, 2000, pp. 105–116.
- Graeme Donald Snooks, "A general theory of complex living systems: Exploring the demand side of dynamics", *Complexity*, vol. 13, no. 6, July/August 2008.

- John N. Warfield, "A proposal for Systems Science", *Systems Research and Behavioral Science*, 20, 2003, pp. 507–520. doi:10.1002/sres.528

External links

- Principia Cybernetica Web (http://pespmc1.vub.ac.be/)
- International Society for the System Sciences (http://isss.org/world/)
- UK Systems Society (http://www.ukss.org.uk)
- (http://www.iitj.ac.in/SS.html)

Systems biology



An illustration of the systems approach to biology

Systems biology is an emerging approach applied to biomedical and biological scientific research. Systems biology is a biology-based inter-disciplinary field of study that focuses on complex interactions within biological systems, using a more holistic perspective (holism instead of the more traditional reductionism) approach to biological and biomedical research. Particularly from year 2000 onwards, the concept has been used widely in the biosciences in a variety of contexts. One of the outreaching aims of systems biology is to model and discover emergent properties, properties of cells, tissues and organisms functioning as a system whose theoretical description is only possible using techniques which fall under the remit of systems biology. These typically involve metabolic networks or cell signaling networks.[1]

Overview

Systems biology can be considered from a number of different aspects:

- As a **field of study**, particularly, the study of the interactions between the components of *biological systems*, and how these interactions give rise to the function and behavior of that system (for example, the enzymes and metabolites in a metabolic pathway).[2][3]
- As a **paradigm**, usually defined in antithesis to the so-called reductionist paradigm (biological organisation), although fully consistent with the scientific method. The distinction between the two paradigms is referred to in these quotations:

  "The reductionist approach has successfully identified most of the components and many of the interactions but, unfortunately, offers no convincing concepts or methods to understand how system properties emerge...the pluralism of causes and effects in biological networks is better addressed by observing, through quantitative measures, multiple components simultaneously and by rigorous data integration with mathematical models" (Sauer *et al.*).[4]

"Systems biology...is about putting together rather than taking apart, integration rather than reduction. It requires that we develop ways of thinking about integration that are as rigorous as our reductionist programmes, but different....It means changing our philosophy, in the full sense of the term" (Denis Noble).[5]

- As a series of **operational protocols used for performing research**, namely a cycle composed of theory, analytic or computational modelling to propose specific testable hypotheses about a biological system, experimental validation, and then using the newly acquired quantitative description of cells or cell processes to refine the computational model or theory.[6] Since the objective is a model of the interactions in a system, the experimental techniques that most suit systems biology are those that are system-wide and attempt to be as complete as possible. Therefore, transcriptomics, metabolomics, proteomics and high-throughput techniques are used to collect quantitative data for the construction and validation of models.
- As the application of dynamical systems theory to molecular biology. Indeed, the focus on the dynamics of the studied systems is the main conceptual difference between systems biology and bioinformatics.
- As a **socioscientific phenomenon** defined by the strategy of pursuing integration of complex data about the interactions in biological systems from diverse experimental sources using interdisciplinary tools and personnel.

This variety of viewpoints is illustrative of the fact that systems biology refers to a cluster of peripherally overlapping concepts rather than a single well-delineated field. However the term has widespread currency and popularity as of 2007, with chairs and institutes of systems biology proliferating worldwide.

History

Systems biology finds its roots in:

- the quantitative modeling of enzyme kinetics, a discipline that flourished between 1900 and 1970,
- the mathematical modeling of population growth,
- the simulations developed to study neurophysiology, and
- control theory and cybernetics.

One of the theorists who can be seen as one of the precursors of systems biology is Ludwig von Bertalanffy with his general systems theory.[7] One of the first numerical simulations in cell biology was published in 1952 by the British neurophysiologists and Nobel prize winners Alan Lloyd Hodgkin and Andrew Fielding Huxley, who constructed a mathematical model that explained the action potential propagating along the axon of a neuronal cell.[8] Their model described a cellular function emerging from the interaction between two different molecular components, a potassium and a sodium channel, and can therefore be seen as the beginning of computational systems biology.[9] In 1960, Denis Noble developed the first computer model of the heart pacemaker.[10]

The formal study of systems biology, as a distinct discipline, was launched by systems theorist Mihajlo Mesarovic in 1966 with an international symposium at the Case Institute of Technology in Cleveland, Ohio entitled "Systems Theory and Biology".[11][12]

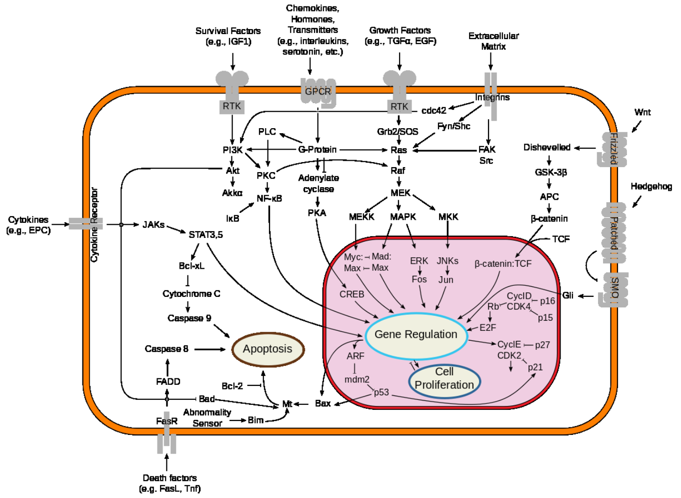
The 1960s and 1970s saw the development of several approaches to study complex molecular systems, such as the Metabolic Control Analysis and the biochemical systems theory. The successes of molecular biology throughout the 1980s, coupled with a skepticism toward theoretical biology, that then promised more than it achieved, caused the quantitative modelling of biological processes to become a somewhat minor field.

However the birth of functional genomics in the 1990s meant that large quantities of high quality data became available, while the computing power exploded, making more realistic models possible. In 1997, the group of Masaru Tomita published the first quantitative model of the metabolism of a whole (hypothetical) cell.[13]

Around the year 2000, after Institutes of Systems Biology were established in Seattle and Tokyo, systems biology emerged as a movement in its own right, spurred on by the completion of various genome projects, the large increase in data from the omics (e.g. genomics and proteomics) and the accompanying advances in high-throughput experiments and bioinformatics. Since then, various research institutes dedicated to systems biology have been

developed. For example, the NIGMS of NIH established a project grant that is currently supporting over ten Systems Biology Centers [14] in the United States. As of summer 2006, due to a shortage of people in systems biology[15] several doctoral training programs in systems biology have been established in many parts of the world. In that same year, the National Science Foundation (NSF) put forward a grand challenge for systems biology in the 21st century to build a mathematical model of the whole cell.[16]

Associated disciplines



Overview of signal transduction pathways

According to the interpretation of Systems Biology as the ability to obtain, integrate and analyze complex data sets from multiple experimental sources using interdisciplinary tools, some typical technology platforms are:

- Phenomics: Organismal variation in phenotype as it changes during its life span.
- Genomics: Organismal deoxyribonucleic acid (DNA) sequence, including intra-organisamal cell specific variation. (i.e. Telomere length variation etc.).
- Epigenomics / Epigenetics: Organismal and corresponding cell specific transcriptomic regulating factors not empirically coded in the genomic sequence. (i.e. DNA methylation, Histone Acetylation etc.).
- Transcriptomics: Organismal, tissue or whole cell gene expression measurements by DNA microarrays or serial analysis of gene expression
- Interferomics: Organismal, tissue, or cell level transcript correcting factors (i.e. RNA interference)
- Translatomics / Proteomics: Organismal, tissue, or cell level measurements of proteins and peptides via two-dimensional gel electrophoresis, mass spectrometry or multi-dimensional protein identification techniques (advanced HPLC systems coupled with mass spectrometry). Sub disciplines include phosphoproteomics, glycoproteomics and other methods to detect chemically modified proteins.
- Metabolomics: Organismal, tissue, or cell level measurements of all small-molecules known as metabolites.
- Glycomics: Organismal, tissue, or cell level measurements of carbohydrates.
- Lipidomics: Organismal, tissue, or cell level measurements of lipids.

In addition to the identification and quantification of the above given molecules further techniques analyze the dynamics and interactions within a cell. This includes:

- Interactomics: Organismal, tissue, or cell level study of interactions between molecules. Currently the authoritative molecular discipline in this field of study is protein-protein interactions (PPI), although the working definition does not preclude inclusion of other molecular disciplines such as those defined here.
- NeuroElectroDynamics: Organismal, brain computing function as a dynamic system, underlying biophysical mechanisms and emerging computation by electrical interactions.
- Fluxomics: Organismal, tissue, or cell level measurements of molecular dynamic changes over time.
- Biomics: systems analysis of the biome.

The investigations are frequently combined with large-scale perturbation methods, including gene-based (RNAi, mis-expression of wild type and mutant genes) and chemical approaches using small molecule libraries. Robots and automated sensors enable such large-scale experimentation and data acquisition. These technologies are still emerging and many face problems that the larger the quantity of data produced, the lower the quality. A wide variety

of quantitative scientists (computational biologists, statisticians, mathematicians, computer scientists, engineers, and physicists) are working to improve the quality of these approaches and to create, refine, and retest the models to accurately reflect observations.

The systems biology approach often involves the development of mechanistic models, such as the reconstruction of dynamic systems from the quantitative properties of their elementary building blocks.[17][18] For instance, a cellular network can be modelled mathematically using methods coming from chemical kinetics and control theory. Due to the large number of parameters, variables and constraints in cellular networks, numerical and computational techniques are often used (e.g., Flux balance analysis).

Other aspects of computer science and informatics are also used in systems biology. These include:

- New forms of computational model, such as the use of process calculi to model biological processes (notable approaches include stochastic π -calculus, BioAmbients, Beta Binders, BioPEPA and Brane calculus) and constraint-based modeling.
- Integration of information from the literature, using techniques of information extraction and text mining.
- Development of online databases and repositories for sharing data and models, approaches to database integration and software interoperability via loose coupling of software, websites and databases, or commercial suits.
- Development of syntactically and semantically sound ways of representing biological models.

References

[1] Bu Z, Callaway DJ (2011). "Proteins MOVE! Protein dynamics and long-range allostery in cell signaling". *Advances in Protein Chemistry and Structural Biology*. Advances in Protein Chemistry and Structural Biology **83**: 163–221. doi:10.1016/B978-0-12-381262-9.00005-7. ISBN 978-0-123-81262-9. PMID 21570668.

[2] Snoep, Jacky L; Westerhoff, Hans V (2005). "From isolation to integration, a systems biology approach for building the Silicon Cell". In Alberghina, Lilia; Westerhoff, Hans V. *Systems Biology: Definitions and Perspectives*. Topics in Current Genetics. **13**. Berlin: Springer-Verlag. pp. 13–30. doi:10.1007/b106456. ISBN 978-3-540-22968-1.

[3] "Systems Biology: the 21st Century Science" (http://www.systemsbiology.org/Intro_to_Systems_Biology/Systems_Biology_--_the_21st_Century_Science). Institute for Systems Biology. . Retrieved 15 June 2011.

[4] Sauer, Uwe; Heinemann, Matthias; Zamboni, Nicola (27 April 2007). "GENETICS: Getting Closer to the Whole Picture". *Science* **316** (5824): 550–551. doi:10.1126/science.1142502. PMID 17463274.

[5] Noble, Denis (2006). *The music of life: Biology beyond the genome*. Oxford: Oxford University Press. pp. 176. ISBN 978-0-19-929573-9.

[6] Kholodenko, Boris N; Sauro, Herbert M (2005). "Mechanistic and modular approaches to modeling and inference of cellular regulatory networks". In Alberghina, Lilia; Westerhoff, Hans V. *Systems Biology: Definitions and Perspectives*. Topics in Current Genetics. **13**. Berlin: Springer-Verlag. pp. 357–451. doi:10.1007/b136809. ISBN 978-3-540-22968-1.

[7] von Bertalanffy, Ludwig (28 March 1976) [1968]. *General System theory: Foundations, Development, Applications*. George Braziller. pp. 295. ISBN 978-0-8076-0453-3.

[8] Hodgkin, Alan L; Huxley, Andrew F (28 August 1952). "A quantitative description of membrane current and its application to conduction and excitation in nerve". *Journal of Physiology* **117** (4): 500–544. PMC 1392413. PMID 12991237.

[9] Le Novère, Nicolas (13 June 2007). "The long journey to a Systems Biology of neuronal function". *BMC Systems Biology* **1**: 28. doi:10.1186/1752-0509-1-28. PMC 1904462. PMID 17567903.

[10] Noble, Denis (5 November 1960). "Cardiac action and pacemaker potentials based on the Hodgkin-Huxley equations". *Nature* **188** (4749): 495–497. Bibcode 1960Natur.188..495N. doi:10.1038/188495b0. PMID 13729365.

[11] Mesarovic, Mihajlo D (1968). *Systems Theory and Biology*. Berlin: Springer-Verlag.

[12] Rosen, Robert (5 July 1968). "A Means Toward a New Holism". *Science* **161** (3836): 34–35. Bibcode 1968Sci...161...34M. doi:10.1126/science.161.3836.34. JSTOR 1724368.

[13] Tomita, Masaru; Hashimoto, Kenta; Takahashi, Kouichi; Shimizu, Thomas S; Matsuzaki, Yuri; Miyoshi, Fumihiko; Saito, Kanako; Tanida, Sakura et al. (1997). "E-CELL: Software Environment for Whole Cell Simulation" (http://web.sfc.keio.ac.jp/~mt/mt-lab/publications/Paper/ecell/bioinfo99/btc007_gml.html). *Genome Inform Ser Workshop Genome Inform* **8**: 147–155. PMID 11072314. . Retrieved 15 June 2011.

[14] http://www.systemscenters.org/

[15] Kling, Jim (3 March 2006). "Working the Systems" (http://sciencecareers.sciencemag.org/career_magazine/previous_issues/articles/2006_03_03/noDOI.15936087948366349051). Science. . Retrieved 15 June 2011.

[16] The American Association for the Advancement of Science (http://www.sciencemag.org/content/314/5806/1696.full)

[17] Gardner, Timothy S; di Bernardo, Diego; Lorenz, David; Collins, James J (4 July 2003). "Inferring Genetic Networks and Identifying Compound Mode of Action via Expression Profiling". *Science* **301** (5629): 102–105. Bibcode 2003Sci...301..102G.

doi:10.1126/science.1081900. PMID 12843395.
[18] di Bernardo, Diego; Thompson, Michael J; Gardner, Timothy S; Chobot, Sarah E; Eastwood, Erin L; Wojtovich, Andrew P; Elliott, Sean J; Schaus, Scott E et al. (March 2005). "Chemogenomic profiling on a genome-wide scale using reverse-engineered gene networks". *Nature Biotechnology* **23** (3): 377–383. doi:10.1038/nbt1075. PMID 15765094.

Further reading

- Kitano, Hiroaki (15 October 2001). *Foundations of Systems Biology*. MIT Press. pp. 320. ISBN 978-0-262-11266-6.
- Werner, Eric (29 March 2007). "All systems go". *Nature* **446** (7135): 493–494. Bibcode 2007Natur.446..493W. doi:10.1038/446493a. provides a comparative review of three books:
  - Alon, Uri (7 July 2006). *An Introduction to Systems Biology: Design Principles of Biological Circuits*. Chapman & Hall. pp. 301. ISBN 978-1-58488-642-6.
  - Kaneko, Kunihiko (15 September 2006). *Life: An Introduction to Complex Systems Biology*. Springer-Verlag. pp. 371. ISBN 978-3-540-32666-3.
  - Palsson, Bernhard O (16 January 2006). *Systems Biology: Properties of Reconstructed Networks*. Cambridge University Press. pp. 334. ISBN 978-0-521-85903-5.

Biology


Biology deals with the study of the many varieties of living organisms. Clockwise from top left: *Salmonella typhimurium*, *Phascolarctos cinereus*, *Athyrium filix-femina*, *Amanita muscaria*, *Agalychnis callidryas*, and *Brachypelma smithi*

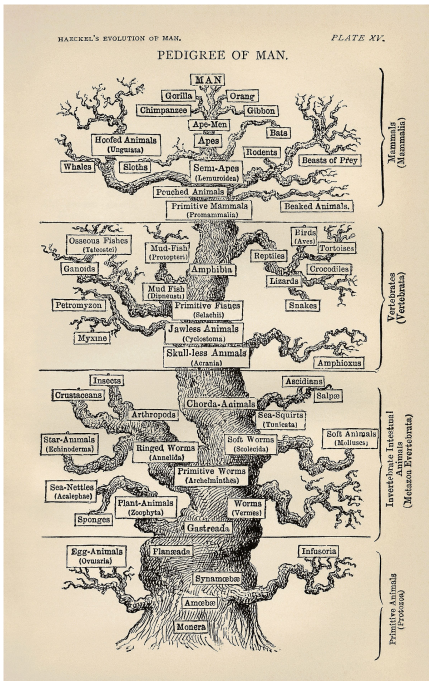
Biology is a natural science concerned with the study of life and living organisms, including their structure, function, growth, origin, evolution, distribution, and taxonomy.[1] Biology is a vast subject containing many subdivisions, topics, and disciplines. Among the most important topics are five unifying principles that can be said to be the fundamental axioms of modern biology:[2]

1. Cells are the basic unit of life
2. New species and inherited traits are the product of evolution
3. Genes are the basic unit of heredity
4. An organism regulates its internal environment to maintain a stable and constant condition
5. Living organisms consume and transform energy.

Subdisciplines of biology are recognized on the basis of the scale at which organisms are studied and the methods used to study them: biochemistry examines the rudimentary chemistry of life; molecular biology studies the complex interactions of systems of biological molecules; cellular biology examines the basic building block of all life, the cell; physiology examines the physical and chemical functions of the tissues, organs, and organ systems

of an organism; evolutionary biology examines the processes that have given rise to the diversity of life; and ecology examines how various organisms interact and associate with their environment.[3]

History



Ernst Haeckel's Tree of Life (1879)

The term *biology* is derived from the Greek word βίος, *bios*, "life" and the suffix -λογία, *-logia*, "study of." [4]The Latin form of the term first appeared in 1736 when Linnaeus (Carl von Linné) used *biologi* in his *Bibliotheca botanica*. It was used again in 1766 in a work entitled *Philosophiae naturalis sive physicae: tomus III, continens geologian, biologian, phytologian generalis*, by Michael Christoph Hanov, a disciple of Christian Wolff. The first German use, *Biologie*, was used in a 1771 translation of Linnaeus' work. In 1797, Theodor Georg Roose used the term in a book, *Grundzüge der Lehre van der Lebenskraft*, in the preface. Karl Friedrich Burdach used the term in 1800 in a more restricted sense of the study of human beings from a morphological, physiological and psychological perspective (*Propädeutik zum Studien der gesammten Heilkunst*). The term came into its modern usage with the six-volume treatise *Biologie, oder Philosophie der lebenden Natur* (1802–22) by Gottfried Reinhold Treviranus, who announced:[5]

> The objects of our research will be the different forms and manifestations of life, the conditions and laws under which these phenomena occur, and the causes through which they have been effected. The science that concerns itself with these objects we will indicate by the name biology [Biologie] or the doctrine of life [Lebenslehre]. (1:4)

Although biology in its modern form is a relatively recent development, sciences related to and included within it have been studied since ancient times. Natural philosophy was studied as early as the ancient civilizations of Mesopotamia, Egypt, the Indian subcontinent, and China. However, the origins of modern biology and its approach to the study of nature are most often traced back to ancient Greece.[6] While the formal study of medicine dates back to Hippocrates (ca. 460 BC – ca. 370 BC), it was Aristotle (384 BC – 322 BC) who contributed most extensively to the development of biology. Especially important are his History of Animals and other works where he showed naturalist leanings, and later more empirical works that focused on biological causation and the diversity of life. Aristotle's successor at the Lyceum, Theophrastus, wrote a series of books on botany that survived as the most important contribution of antiquity to the plant sciences, even into the Middle Ages.

Scholars of the medieval Islamic world who wrote on biology included al-Jahiz (781–869), Al-Dinawari (828–896), who wrote on botany,[7] and Rhazes (865–925) who wrote on anatomy and physiology. Medicine was especially well studied by Islamic scholars working in Greek philosopher traditions, while natural history drew heavily on Aristotelian thought, especially in upholding a fixed hierarchy of life.

Biology began to quickly develop and grow with Antony van Leeuwenhoek's dramatic improvement of the microscope. It was then that scholars discovered spermatozoa, bacteria, infusoria and the sheer strangeness and diversity of microscopic life. Investigations by Jan Swammerdam led to new interest in entomology and built the basic techniques of microscopic dissection and staining.[8]

Advances in microscopy also had a profound impact on biological thinking itself. In the early 19th century, a number of biologists pointed to the central importance of the cell. In 1838 and 1839, Schleiden and Schwann began promoting the ideas that (1) the basic unit of organisms is the cell and (2) that individual cells have all the characteristics of life, although they opposed the idea that (3) all cells come from the division of other cells. Thanks

to the work of Robert Remak and Rudolf Virchow, however, by the 1860s most biologists accepted all three tenets of what came to be known as cell theory.[9]

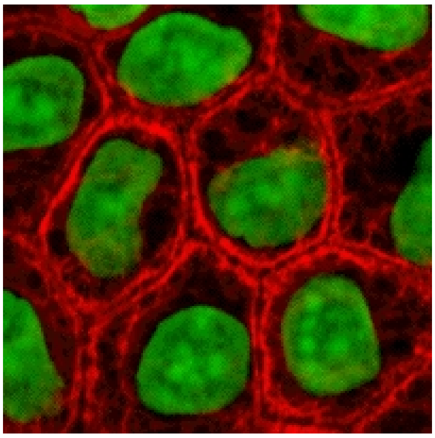
Meanwhile, taxonomy and classification became a focus in the study of natural history. Carolus Linnaeus published a basic taxonomy for the natural world in 1735 (variations of which have been in use ever since), and in the 1750s introduced scientific names for all his species.[10] Georges-Louis Leclerc, Comte de Buffon, treated species as artificial categories and living forms as malleable—even suggesting the possibility of common descent. Though he was opposed to evolution, Buffon is a key figure in the history of evolutionary thought; his work influenced the evolutionary theories of both Lamarck and Darwin.[11]

Serious evolutionary thinking originated with the works of Jean-Baptiste Lamarck. However, it was the British naturalist Charles Darwin, combining the biogeographical approach of Humboldt, the uniformitarian geology of Lyell, Thomas Malthus's writings on population growth, and his own morphological expertise, that created a more successful evolutionary theory based on natural selection; similar reasoning and evidence led Alfred Russel Wallace to independently reach the same conclusions.[12]

The discovery of the physical representation of heredity came along with evolutionary principles and population genetics. In the 1940s and early 1950s, experiments pointed to DNA as the component of chromosomes that held genes. A focus on new model organisms such as viruses and bacteria, along with the discovery of the double helical structure of DNA in 1953, marked the transition to the era of molecular genetics. From the 1950s to present times, biology has been vastly extended in the molecular domain. The genetic code was cracked by Har Gobind Khorana, Robert W. Holley and Marshall Warren Nirenberg after DNA was understood to contain codons. Finally, the Human Genome Project was launched in 1990 with the goal of mapping the general human genome. This project was essentially completed in 2003,[13] with further analysis still being published. The Human Genome Project was the first step in a globalized effort to incorporate accumulated knowledge of biology into a functional, molecular definition of the human body and the bodies of other organisms.

Foundations of modern biology

Much of modern biology can be encompassed within five unifying principles: cell theory, evolution, genetics, homeostasis, and energy.[2]

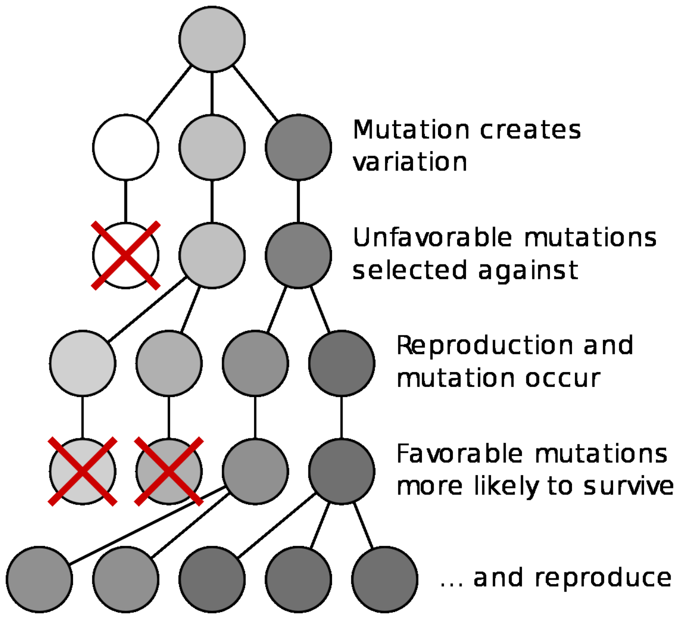


Cells in culture, stained for keratin (red) and DNA (green)

Cell theory

Cell theory states that the cell is the fundamental unit of life, and that all living things are composed of one or more cells or the secreted products of those cells (e.g. shells). All cells arise from other cells through cell division. In multicellular organisms, every cell in the organism's body derives ultimately from a single cell in a fertilized egg. The cell is also considered to be the basic unit in many pathological processes.[14] Additionally, the phenomenon of energy flow occurs in cells in processes that are part of the function known as metabolism. Finally, cells contain hereditary information (DNA) which is passed from cell to cell during cell division.

Evolution



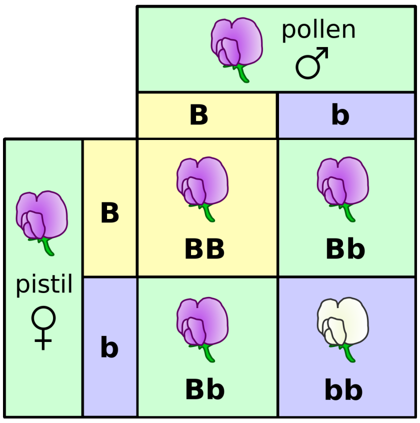
Natural selection of a population for dark coloration.

A central organizing concept in biology is that life changes and develops through evolution, and that all life-forms known have a common origin. Introduced into the scientific lexicon by Jean-Baptiste de Lamarck in 1809,[15] evolution was established by Charles Darwin fifty years later as a viable scientific model when he articulated its driving force: natural selection.[16][17] (Alfred Russel Wallace is recognized as the co-discoverer of this concept as he helped research and experiment with the concept of evolution.)[18] Evolution is now used to explain the great variations of life found on Earth.

Darwin theorized that species and breeds developed through the processes of natural selection and artificial selection or selective breeding.[19] Genetic drift was embraced as an additional mechanism of evolutionary development in the modern synthesis of the theory.[20]

The evolutionary history of the species—which describes the characteristics of the various species from which it descended—together with its genealogical relationship to every other species is known as its phylogeny. Widely varied approaches to biology generate information about phylogeny. These include the comparisons of DNA sequences conducted within molecular biology or genomics, and comparisons of fossils or other records of ancient organisms in paleontology.[21] Biologists organize and analyze evolutionary relationships through various methods, including phylogenetics, phenetics, and cladistics. (For a summary of major events in the evolution of life as currently understood by biologists, see evolutionary timeline.)

The theory of evolution postulates that all organisms on the Earth, both living and extinct, have descended from a common ancestor or an ancestral gene pool. This last universal common ancestor of all organisms is believed to have appeared about 3.5 billion years ago.[22] Biologists generally regard the universality and ubiquity of the genetic code as definitive evidence in favor of the theory of universal common descent for all bacteria, archaea, and eukaryotes (see: origin of life).[23]



A Punnett square depicting a cross between two pea plants heterozygous for purple (B) and white (b) blossoms

Genetics

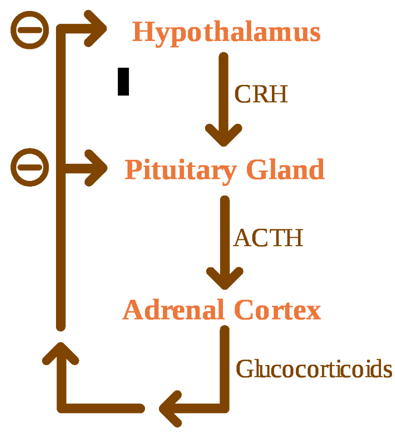
Genes are the primary units of inheritance in all organisms. A gene is a unit of heredity and corresponds to a region of DNA that influences the form or function of an organism in specific ways. All organisms, from bacteria to animals, share the same basic machinery that copies and translates DNA into proteins. Cells transcribe a DNA gene into an RNA version of the gene, and a ribosome then translates the RNA into a protein, a sequence of amino acids. The translation code from RNA codon to amino acid is the same for most organisms, but slightly different for some. For example, a sequence of DNA that codes for insulin in humans also codes for insulin when inserted into other organisms, such as plants.[24][25]

DNA usually occurs as linear chromosomes in eukaryotes, and circular chromosomes in prokaryotes. A chromosome is an organized structure consisting of DNA and histones. The set of chromosomes in a cell and any other hereditary information found in the mitochondria, chloroplasts, or other locations is collectively known as its genome. In eukaryotes, genomic DNA is located in the cell nucleus, along with small amounts in mitochondria and chloroplasts. In prokaryotes, the DNA is held within an irregularly shaped body in the cytoplasm called the nucleoid.[26] The genetic information in a genome is held within genes, and the complete assemblage of this information in an organism is called its genotype.[27]

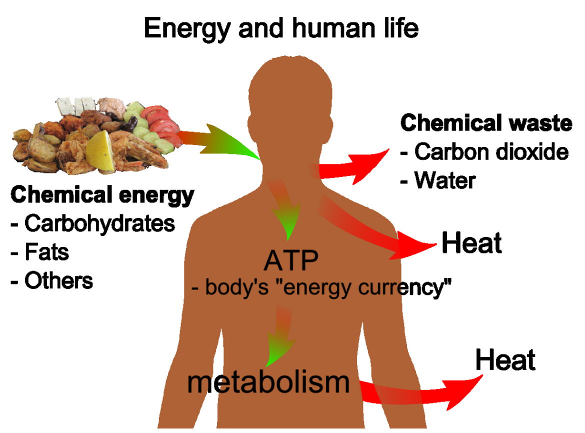
Homeostasis

Homeostasis is the ability of an open system to regulate its internal environment to maintain stable conditions by means of multiple dynamic equilibrium adjustments controlled by interrelated regulation mechanisms. All living organisms, whether unicellular or multicellular, exhibit homeostasis.[29]

To maintain dynamic equilibrium and effectively carry out certain functions, a system must detect and respond to perturbations. After the detection of a perturbation, a biological system normally respond through negative feedback. This means stabilizing conditions by either reducing or increasing the activity of an organ or system. One example is the release of glucagon when sugar levels are too low.



The hypothalamus secretes CRH, which directs the pituitary gland to secrete ACTH. In turn, ACTH directs the adrenal cortex to secrete glucocorticoids, such as cortisol. The GCs then reduce the rate of secretion by the hypothalamus and the pituitary gland once a sufficient amount of GCs has been released.[28]



Basic overview of energy and human life.

Energy

The survival of a living organism depends on the continuous input of energy. Chemical reactions that are responsible for its structure and function are tuned to extract energy from substances that act as its food and transform them to help form new cells and sustain them. In this process, molecules of chemical substances that constitute food play two roles; first, they contain energy that can be transformed for biological chemical reactions; second, they develop new molecular structures made up of biomolecules.

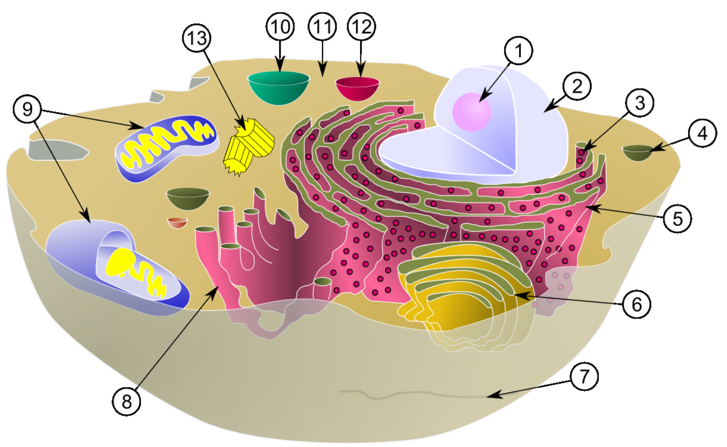
The organisms responsible for the introduction of energy into an ecosystem are known as producers or autotrophs. Nearly all of these organisms originally draw energy from the sun.[30] Plants and other phototrophs use solar energy via a process known as photosynthesis to convert raw materials into organic molecules, such as ATP, whose bonds can be broken to release energy.[31] A few ecosystems, however, depend entirely on energy extracted by chemotrophs from methane, sulfides, or other non-luminal energy sources.[32]

Some of the captured energy is used to produce biomass to sustain life and provide energy for growth and development. The majority of the rest of this energy is lost as heat and waste molecules. The most important processes for converting the energy trapped in chemical substances into energy useful to sustain life are metabolism[33] and cellular respiration.[34]

Research

Structural

Molecular biology is the study of biology at a molecular level.[35] This field overlaps with other areas of biology, particularly with genetics and biochemistry. Molecular biology chiefly concerns itself with understanding the interactions between the various systems of a cell, including the interrelationship of DNA, RNA, and protein synthesis and learning how these interactions are regulated.



Schematic of typical animal cell depicting the various organelles and structures.

Cell biology studies the structural and physiological properties of cells, including their behaviors, interactions, and environment. This is done on both the microscopic and molecular levels, for single-celled organisms such as bacteria as well as the specialized cells in multicellular organisms such as humans. Understanding the structure and function of cells is fundamental to all of the biological sciences. The similarities and differences between cell types are particularly relevant to molecular biology.

Anatomy considers the forms of macroscopic structures such as organs and organ systems.[36]

Genetics is the science of genes, heredity, and the variation of organisms.[37][38] Genes encode the information necessary for synthesizing proteins, which in turn play a large role in influencing (though, in many instances, not completely determining) the final phenotype of the organism. In modern research, genetics provides important tools in the investigation of the function of a particular gene, or the analysis of genetic interactions. Within organisms, genetic information generally is carried in chromosomes, where it is represented in the chemical structure of particular DNA molecules.

Developmental biology studies the process by which organisms grow and develop. Originating in embryology, modern developmental biology studies the genetic control of cell growth, differentiation, and "morphogenesis," which is the process that progressively gives rise to tissues, organs, and anatomy. Model organisms for developmental biology include the round worm *Caenorhabditis elegans,*[39] the fruit fly *Drosophila melanogaster,*[40] the zebrafish *Danio rerio,*[41] the mouse *Mus musculus,*,[42] and the weed *Arabidopsis thaliana*.[43][44] (A model organism is a species that is extensively studied to understand particular biological phenomena, with the expectation that discoveries made in that organism provide insight into the workings of other organisms.)[45]

Physiological

Physiology studies the mechanical, physical, and biochemical processes of living organisms by attempting to understand how all of the structures function as a whole. The theme of "structure to function" is central to biology. Physiological studies have traditionally been divided into plant physiology and animal physiology, but some principles of physiology are universal, no matter what particular organism is being studied. For example, what is learned about the physiology of yeast cells can also apply to human cells. The field of animal physiology extends the tools and methods of human physiology to non-human species. Plant physiology borrows techniques from both research fields.

Physiology studies how for example nervous, immune, endocrine, respiratory, and circulatory systems, function and interact. The study of these systems is shared with medically oriented disciplines such as neurology and immunology.

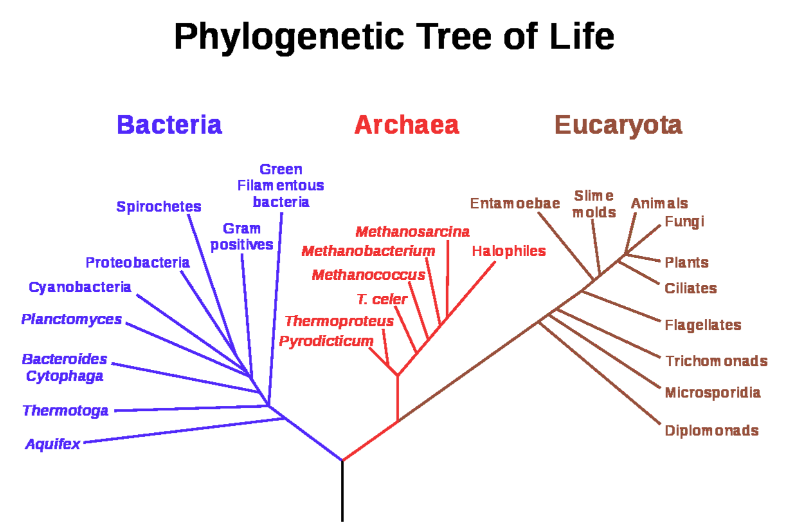
Evolutionary

Evolutionary research is concerned with the origin and descent of species, as well as their change over time, and includes scientists from many taxonomically oriented disciplines. For example, it generally involves scientists who have special training in particular organisms such as mammalogy, ornithology, botany, or herpetology, but use those organisms as systems to answer general questions about evolution.

Evolutionary biology is partly based on paleontology, which uses the fossil record to answer questions about the mode and tempo of evolution,[46] and partly on the developments in areas such as population genetics[47] and evolutionary theory. In the 1980s, developmental biology re-entered evolutionary biology from its initial exclusion from the modern synthesis through the study of evolutionary developmental biology.[48] Related fields often considered part of evolutionary biology are phylogenetics, systematics, and taxonomy.

Systematics

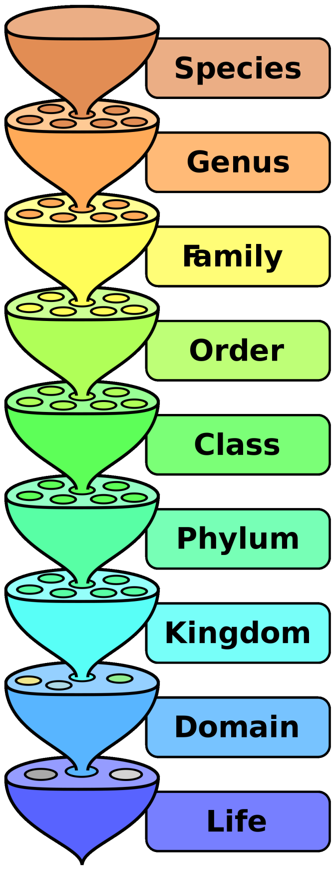
Multiple speciation events create a tree structured system of relationships between species. The role of systematics is to study these relationships and thus the differences and similarities between species and groups of species.[49] However, systematics was an active field of research long before evolutionary thinking was common.[50] The classification, taxonomy, and nomenclature of biological organisms is administered by the International Code of Zoological Nomenclature, International Code of Botanical Nomenclature, and International Code of Nomenclature of Bacteria for animals, plants, and bacteria, respectively. The classification of viruses, viroids, prions, and all other sub-viral agents that demonstrate biological characteristics is conducted by the International Code of Virus classification and nomenclature.[51][52][53][54] However, several other viral classification systems do exist.



A phylogenetic tree of all living things, based on rRNA gene data, showing the separation of the three domains bacteria, archaea, and eukaryotes as described initially by Carl Woese. Trees constructed with other genes are generally similar, although they may place some early-branching groups very differently, presumably owing to rapid rRNA evolution. The exact relationships of the three domains are still being debated.

Traditionally, living things have been divided into five kingdoms: Monera; Protista; Fungi; Plantae; Animalia.[55]

However, many scientists now consider this five-kingdom system outdated. Modern alternative classification systems generally begin with the three-domain system: Archaea (originally Archaebacteria); Bacteria (originally Eubacteria); Eukaryota (including protists, fungi, plants, and animals)[56] These domains reflect whether the cells have nuclei or not, as well as differences in the chemical composition of the cell exteriors.[56]



The hierarchy of biological classification's eight major taxonomic ranks. Intermediate minor rankings are not shown. This diagram use a 3 Domains / 6 Kingdoms format

Further, each kingdom is broken down recursively until each species is separately classified. The order is: Domain; Kingdom; Phylum; Class; Order; Family; Genus; Species.

There is also a series of intracellular parasites that are "on the edge of life"[57] in terms of metabolic activity, meaning that many scientists do not actually classify these structures as alive, due to their lack of at least one or more of the fundamental functions that define life. They are classified as viruses, viroids, prions, or satellites.

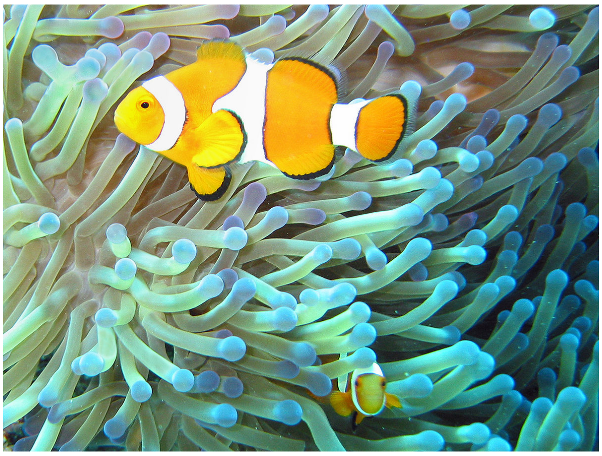
The scientific name of an organism is generated from its genus and species. For example, humans are listed as *Homo sapiens*. *Homo* is the genus, and *sapiens* the species. When writing the scientific name of an organism, it is proper to capitalize the first letter in the genus and put all of the species in lowercase. Additionally, the entire term may be italicized or underlined.[58][59]

The dominant classification system is called the Linnaean taxonomy. It includes ranks and binomial nomenclature. How organisms are named is governed by international agreements such as the International Code of Botanical Nomenclature (ICBN), the International Code of Zoological Nomenclature (ICZN), and the International Code of Nomenclature of Bacteria (ICNB).

A merging draft, BioCode, was published in 1997 in an attempt to standardize nomenclature in these three areas, but has yet to be formally adopted.[60] The BioCode draft has received little attention since 1997; its originally planned implementation date of January 1, 2000, has passed unnoticed. However, a 2004 paper concerning the cyanobacteria does advocate a future adoption of a BioCode and interim steps consisting of reducing the differences between the codes.[61] The International Code of Virus Classification and Nomenclature (ICVCN) remains outside the BioCode.

Ecology

Ecology studies the distribution and abundance of living organisms, and the interactions between organisms and their environment.[62] The habitat of an organism can be described as the local abiotic factors such as climate and ecology, in addition to the other organisms and biotic factors that share its environment.[63] One reason that biological systems can be difficult to study is that so many different interactions with other organisms and the environment are possible, even on the smallest of scales. A microscopic bacterium responding to a local sugar gradient is responding to its environment as much as a lion is responding to its environment when it searches for food in the African savanna. For any given species, behaviors can be co-operative, aggressive, parasitic, or symbiotic. Matters become more complex when two or more different species interact in an ecosystem. Studies of this type are within the province of ecology.



Mutual symbiosis between clownfish of the genus Amphiprion that dwell among the tentacles of tropical sea anemones. The territorial fish protects the anemone from anemone-eating fish, and in turn the stinging tentacles of the anemone protects the clown fish from its predators

Ecological systems are studied at several different levels, from individuals and populations to ecosystems and the biosphere. The term population biology is often used interchangeably with population ecology, although *population biology* is more frequently used when studying diseases, viruses, and microbes, while population ecology is more commonly when studying plants and animals. As can be surmised, ecology is a science that draws on several disciplines.

Ethology studies animal behavior (particularly that of social animals such as primates and canids), and is sometimes considered a branch of zoology. Ethologists have been particularly concerned with the evolution of behavior and the understanding of behavior in terms of the theory of natural selection. In one sense, the first modern ethologist was Charles Darwin, whose book, *The Expression of the Emotions in Man and Animals,* influenced many ethologists to come.[64]

Biogeography studies the spatial distribution of organisms on the Earth,[65] focusing on topics like plate tectonics, climate change, dispersal and migration, and cladistics.

Branches of biology

These are the main branches of biology:[66][67]

- Aerobiology – the study of airborne organic particles
- Agriculture – the study of producing crops from the land, with an emphasis on practical applications
- Anatomy – the study of form and function, in plants, animals, and other organisms, or specifically in humans
- Arachnology – the study of arachnids
- Astrobiology – the study of evolution, distribution, and future of life in the universe—also known as exobiology, exopaleontology, and bioastronomy
- Biochemistry – the study of the chemical reactions required for life to exist and function, usually a focus on the cellular level
- Bioengineering – the study of biology through the means of engineering with an emphasis on applied knowledge and especially related to biotechnology
- Biogeography – the study of the distribution of species spatially and temporally

- Bioinformatics – the use of information technology for the study, collection, and storage of genomic and other biological data
- Biomathematics (or Mathematical biology) – the quantitative or mathematical study of biological processes, with an emphasis on modeling
- Biomechanics – often considered a branch of medicine, the study of the mechanics of living beings, with an emphasis on applied use through prosthetics or orthotics
- Biomedical research – the study of the human body in health and disease
- Biophysics – the study of biological processes through physics, by applying the theories and methods traditionally used in the physical sciences
- Biotechnology – a new and sometimes controversial branch of biology that studies the manipulation of living matter, including genetic modification and synthetic biology
- Building biology – the study of the indoor living environment
- Botany – the study of plants
- Cell biology – the study of the cell as a complete unit, and the molecular and chemical interactions that occur within a living cell
- Conservation biology – the study of the preservation, protection, or restoration of the natural environment, natural ecosystems, vegetation, and wildlife
- Cryobiology – the study of the effects of lower than normally preferred temperatures on living beings
- Developmental biology – the study of the processes through which an organism forms, from zygote to full structure
- Ecology – the study of the interactions of living organisms with one another and with the non-living elements of their environment
- Embryology – the study of the development of embryo (from fecundation to birth)
- Entomology – the study of insects
- Environmental biology – the study of the natural world, as a whole or in a particular area, especially as affected by human activity
- Epidemiology – a major component of public health research, studying factors affecting the health of populations
- Epigenetics – the study of heritable changes in gene expression or cellular phenotype caused by mechanisms other than changes in the underlying DNA sequence
- Ethology – the study of animal behavior
- Evolutionary biology – the study of the origin and descent of species over time
- Genetics – the study of genes and heredity
- Herpetology – the study of reptiles and amphibians
- Histology – the study of cells and tissues, a microscopic branch of anatomy
- Ichthyology – the study of fish
- Integrative biology – the study of whole organisms
- Limnology – the study of inland waters
- Mammalogy – the study of mammals
- Marine biology (or Biological oceanography) – the study of ocean ecosystems, plants, animals, and other living beings
- Microbiology – the study of microscopic organisms (microorganisms) and their interactions with other living things
- Molecular biology – the study of biology and biological functions at the molecular level, some cross over with biochemistry
- Mycology – the study of fungi
- Neurobiology – the study of the nervous system, including anatomy, physiology and pathology

- Oncology – the study of cancer processes, including virus or mutation oncogenesis, angiogenesis and tissues remoldings
- Ornithology – the study of birds
- Population biology – the study of groups of conspecific organisms, including
  - Population ecology – the study of how population dynamics and extinction
  - Population genetics – the study of changes in gene frequencies in populations of organisms
- Paleontology – the study of fossils and sometimes geographic evidence of prehistoric life
- Pathobiology or pathology – the study of diseases, and the causes, processes, nature, and development of disease
- Parasitology – the study of parasites and parasitism
- Pharmacology – the study and practical application of preparation, use, and effects of drugs and synthetic medicines
- Physiology – the study of the functioning of living organisms and the organs and parts of living organisms
- Phytopathology – the study of plant diseases (also called Plant Pathology)
- Psychobiology – the study of the biological bases of psychology
- Sociobiology – the study of the biological bases of sociology
- Structural biology – a branch of molecular biology, biochemistry, and biophysics concerned with the molecular structure of biological macromolecules
- Synthetic Biology- research integrating biology and engineering; construction of biological functions not found in nature
- Virology – the study of viruses and some other virus-like agents
- Zoology – the study of animals, including classification, physiology, development, and behavior (branches include: Entomology, Ethology, Herpetology, Ichthyology, Mammalogy, and Ornithology)

Notes and references

[1] Based on definition from Aquarena Wetlands Project glossary of terms. (http://www.bio.txstate.edu/~wetlands/Glossary/glossary.html)
[2] Avila, Vernon L. (1995). *Biology: Investigating life on earth*. Boston: Jones and Bartlett. pp. 11–18. ISBN 0-86720-942-9.
[3] Life Science, Weber State Museum of Natural Science (http://community.weber.edu/sciencemuseum/pages/life_main.asp)
[4] "Who coined the term biology?" (http://topics.info.com/Who-coined-the-term-biology_716). *Info.com*. . Retrieved 2012-06-03.
[5] Richards, Robert J. (2002). *The Romantic Conception of Life: Science and Philosophy in the Age of Goethe* (http://books.google.ca/books?id=X7N4_i7vrTUC&printsec=frontcover&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false). University of Chicago Press. ISBN 0-226-71210-9. .
[6] Magner, *A History of the Life Sciences*
[7] Fahd, Toufic. "Botany and agriculture". p. 815., in Morelon, Régis; Rashed, Roshdi (1996). *Encyclopedia of the History of Arabic Science*. **3**. Routledge. ISBN 0415124107
[8] Magner, *A History of the Life Sciences*, pp 133–144
[9] Sapp, *Genesis*, chapter 7; Coleman, *Biology in the Nineteenth Century*, chapters 2
[10] Mayr, *The Growth of Biological Thought*, chapter 4
[11] Mayr, *The Growth of Biological Thought*, chapter 7
[12] Mayr, *The Growth of Biological Thought*, chapter 10: "Darwin's evidence for evolution and common descent"; and chapter 11: "The causation of evolution: natural selection"; Larson, *Evolution*, chapter 3
[13] Noble, Ivan (2003-04-14). "BBC NEWS | Science/Nature | Human genome finally complete" (http://news.bbc.co.uk/1/hi/sci/tech/2940601.stm). *BBC News*. . Retrieved 2006-07-22.
[14] Mazzarello, P (1999). "A unifying concept: the history of cell theory". *Nature Cell Biology* **1** (1): E13–E15. doi:10.1038/8964. PMID 10559875.
[15] Packard, Alpheus Spring (1901). *Lamarck, the founder of Evolution: his life and work with translations of his writings on organic evolution*. New York: Longmans, Green.. ISBN 0405125623.
[16] The Complete Works of Darwin Online – Biography. (http://darwin-online.org.uk/biography.html) *darwin-online.org.uk*. Retrieved on 2006-12-15
Dobzhansky 1973
[17] As Darwinian scholar Joseph Carroll of the University of Missouri–St. Louis puts it in his introduction to a modern reprint of Darwin's work: "*The Origin of Species* has special claims on our attention. It is one of the two or three most significant works of all time—one of those works that fundamentally and permanently alter our vision of the world....It is argued with a singularly rigorous consistency but it is also

eloquent, imaginatively evocative, and rhetorically compelling." Carroll, Joseph, ed. (2003). *On the origin of species by means of natural selection*. Peterborough, Ontario: Broadview. p. 15. ISBN 1551113376.

[18] Shermer p. 149.

[19] Darwin, Charles (1859). On the Origin of Species, 1st, John Murray

[20] Simpson, George Gaylord (1967). *The Meaning of Evolution* (Second ed.). Yale University Press. ISBN 0300009526.

[21] Phylogeny on bio-medicine.org (http://www.bio-medicine.org/q-more/biology-definition/phylogeny/)

[22] De Duve, Christian (2002). *Life Evolving: Molecules, Mind, and Meaning*. New York: Oxford University Press. p. 44. ISBN 0195156056.

[23] Futuyma, DJ (2005). *Evolution*. Sinauer Associates. ISBN 978-0878931873. OCLC 57311264 57638368 62621622.

[24] From SemBiosys, A New Kind Of Insulin (http://www.businessweek.com/magazine/content/07_33/b4046083.htm) INSIDE WALL STREET By Gene G. Marcial(AUGUST 13, 2007)

[25] http://www.i-sis.org.uk/gmSafflowеHumanPro-Insulin.php

[26] Thanbichler M, Wang S, Shapiro L (2005). "The bacterial nucleoid: a highly organized and dynamic structure". *J Cell Biochem* **96** (3): 506–21. doi:10.1002/jcb.20519. PMID 15988757.

[27] Genotype definition – Medical Dictionary definitions (http://www.medterms.com/script/main/art.asp?articlekey=8472)

[28] Raven, PH; Johnson, GB. *Biology*, Fifth Edition, Boston: Hill Companies, Inc. 1999. page 1058.

[29] Kelvin Rodolfo, Explanation of Homeostasis on scientificamerican.com (http://www.scientificamerican.com/article.cfm?id=what-is-homeostasis). Retrieved Oct. 16, 2009.

[30] D.A. Bryant & N.-U. Frigaard (November 2006). "Prokaryotic photosynthesis and phototrophy illuminated". *Trends Microbiol* **14** (11): 488–96. doi:10.1016/j.tim.2006.09.001. PMID 16997562.

[31] Smith, A. L. (1997). *Oxford dictionary of biochemistry and molecular biology*. Oxford [Oxfordshire]: Oxford University Press. p. 508. ISBN 0-19-854768-4. "Photosynthesis – the synthesis by organisms of organic chemical compounds, esp. carbohydrates, from carbon dioxide using energy obtained from light rather than the oxidation of chemical compounds."

[32] Katrina Edwards. *Microbiology of a Sediment Pond and the Underlying Young, Cold,* Hydrologically Active Ridge Flank. *Woods Hole Oceanographic Institution.*

[33] Campbell, Neil A. and Reece Jane B (2001). "6". *Biology*. Benjamin Cummings. ISBN 978-0805366242. OCLC 47521441 48195194 53439122 55707478 64759228 79136407.

[34] Bartsch/Colvard, *The Living Environment*. (2009) New York State Prentice Hall Regents Review. Retrieved Oct. 16, 2009.

[35] Molecular Biology – Definition from biology-online.org (http://www.biology-online.org/dictionary/Molecular_biology)

[36] "Anatomy of the Human Body". (http://www.bartleby.com/107/1.html) 20th edition. 1918. Henry Gray.

[37] Anthony J. F. Griffiths .... (2000). "Genetics and the Organism: Introduction" (http://www.ncbi.nlm.nih.gov/books/bv.fcgi?rid=iga.section.60). In Griffiths, William M.; Miller, Jeffrey H.; Suzuki, David T. et al.. *An Introduction to Genetic Analysis* (7th ed.). New York: W. H. Freeman. ISBN 0-7167-3520-2. .

[38] Hartl D, Jones E (2005)

[39] Brenner, S. (May 1974). "The Genetics of CAENORHABDITIS ELEGANS" (http://dev.wormbase.org/papers/31_Brenner74.pdf) (PDF). *Genetics* **77** (1): 71–94. PMC 1213120. PMID 4366476. .

[40] Eric C. R. Reeve, ed. (2001-06-23). "Drosophila melanogaster: The Fruit Fly" (http://books.google.com/?id=JjLWYKqehRsC&pg=PA157&lpg=PA157&dq=drosophila+eggs+day+lifetime). *Encyclopedia of genetics*. USA: Fitzroy Dearborn Publishers, I. pp. 157. ISBN 9781884964343. . Retrieved 2009-07-01.

[41] Haffter P, Nüsslein-Volhard C (1996). "Large scale genetics in a small vertebrate, the zebrafish" (http://www.intjdevbiol.com/paper.php?doi=8735932). *Int. J. Dev. Biol.* **40** (1): 221–7. PMID 8735932. .

[42] Keller G (2005). "Embryonic stem cell differentiation: emergence of a new era in biology and medicine" (http://genesdev.cshlp.org/content/19/10/1129.long). *Genes Dev.* **19** (10): 1129–55. doi:10.1101/gad.1303605. PMID 15905405. .

[43] Rensink WA, Buell CR (2004). "Arabidopsis to Rice. Applying Knowledge from a Weed to Enhance Our Understanding of a Crop Species". *Plant Physiol.* **135** (2): 622–9. doi:10.1104/pp.104.040170. PMC 514098. PMID 15208410.

[44] Coelho SM, Peters AF, Charrier B, *et al* (2007). "Complex life cycles of multicellular eukaryotes: new approaches based on the use of model organisms". *Gene* **406** (1–2): 152–70. doi:10.1016/j.gene.2007.07.025. PMID 17870254.

[45] Fields S, Johnston M (Mar 2005). "Cell biology. Whither model organism research?" (http://www.sciencemag.org/cgi/content/summary/307/5717/1885). *Science* **307** (5717): 1885–6. doi:10.1126/science.1108872. PMID 15790833. .

[46] Jablonski D (1999). "The future of the fossil record". *Science* **284** (5423): 2114–16. doi:10.1126/science.284.5423.2114. PMID 10381868.

[47] John H. Gillespie Population Genetics: A Concise Guide, Johns Hopkins Press, 1998. ISBN 0-8018-5755-4.

[48] Vassiliki Betta Smocovitis Unifiying Biology: the evolutionary synthesis and evolutionary biology ISBN 0-691-03343-9.

[49] Neill, Campbell (1996). *Biology; Fourth edition*. The Benjamin/Cummings Publishing Company. p. G-21 (Glossary). ISBN 0-8053-1940-9.

[50] Douglas, Futuyma (1998). *Evolutionary Biology; Third edition*. Sinauer Associates. p. 88. ISBN 0-87893-189-9.

[51] ICTV Virus Taxonomy 2009 (http://www.ictvonline.org/virusTaxonomy.asp)

[52] "80.001 Popsiviroidae – ICTVdB Index of Viruses." (http://www.ncbi.nlm.nih.gov/ICTVdb/Ictv/fs_pospi.htm) (Website.) U.S. National Institutes of Health website. Retrieved on 2009-10-28.

[53] "90. Prions – ICTVdB Index of Viruses." (http://www.ncbi.nlm.nih.gov/ICTVdb/Ictv/fs_prion.htm) (Website.) U.S. National Institutes of Health website. Retrieved on 2009-10-28.

[54] "81. Satellites – ICTVdB Index of Viruses." (http://www.ncbi.nlm.nih.gov/ICTVdb/Ictv/fs_satel.htm) (Website.) U.S. National Institutes of Health website. Retrieved on 2009-10-28.
[55] Margulis, L; Schwartz, KV (1997). *Five Kingdoms: An Illustrated Guide to the Phyla of Life on Earth* (3rd ed.). WH Freeman & Co. ISBN 978-0716731832. OCLC 223623098 237138975.
[56] Woese C, Kandler O, Wheelis M (1990). "Towards a natural system of organisms: proposal for the domains Archaea, Bacteria, and Eucarya" (http://www.pnas.org/cgi/reprint/87/12/4576). *Proc Natl Acad Sci USA* **87** (12): 4576–9. Bibcode 1990PNAS...87.4576W. doi:10.1073/pnas.87.12.4576. PMC 54159. PMID 2112744. .
[57] Rybicki EP (1990). "The classification of organisms at the edge of life, or problems with virus systematics". *S Aft J Sci* **86**: 182–186.
[58] Heather Silyn-Roberts (2000). *Writing for Science and Engineering: Papers, Presentation* (http://books.google.com/?id=hVUU7Gq8QskC&lpg=PA198&dq=species epithet capitalize&pg=PA198#v=onepage&q=species epithet capitalize). Oxford: Butterworth-Heinemann. p. 198. ISBN 0750646365. .
[59] "Recommendation 60F" (http://ibot.sav.sk/icbn/frameset/0065Ch7OaGoNSec1a60.htm#recF). *International Code of Botanical Nomenclature, Vienna Code*. 2006. pp. 60F.1. .
[60] John McNeill (1996-11-04). "The BioCode: Integrated biological nomenclature for the 21st century?". *Proceedings of a Mini-Symposium on Biological Nomenclature in the 21st Century*.
[61] Ahoren Oren (2004). "A proposal for further integration of the cyanobacteria under the Bacteriological Code". *Int. J. Syst. Evol. Microbiol.* **54** (Pt 5): 1895–1902. doi:10.1099/ijs.0.03008-0. PMID 15388760.
[62] Begon, M.; Townsend, C. R., Harper, J. L. (2006). *Ecology: From individuals to ecosystems. (4th ed.)*. Blackwell. ISBN 1405111178.
[63] *Habitats of the world* (http://books.google.com/?id=U-_mlcy8rGgC&pg=PA238). New York: Marshall Cavendish. 2004. p. 238. ISBN 978-0-7614-7523-1. .
[64] Black, J (Jun 2002). "Darwin in the world of emotions" (http://www.jrsm.org/cgi/pmidlookup?view=long&pmid=12042386) (Free full text). *Journal of the Royal Society of Medicine* **95** (6): 311–3. doi:10.1258/jrsm.95.6.311. ISSN 0141-0768. PMC 1279921. PMID 12042386. .
[65] Wiley, 1981
[66] Branches of Biology on biology-online.org (http://www.biology-online.org/dictionary/Branches_of_biology)
[67] Biology on bellaonline.com (http://www.bellaonline.com/articles/art28786.asp)

Further reading

- Alberts, Bruce; Johnson, A, Lewis, J, Raff, M, Roberts, K & Walter, P (2002). *Molecular Biology of the Cell* (4th ed.). Garland. ISBN 978-0815332183. OCLC 145080076 48122761 57023651 69932405.
- Begon, Michael; Townsend, CR & Harper, JL (2005). *Ecology: From Individuals to Ecosystems* (4th ed.). Blackwell Publishing Limited. ISBN 978-1405111171. OCLC 57639896 57675855 62131207.
- Campbell, Neil (2004). *Biology* (7th ed.). Benjamin-Cummings Publishing Company. ISBN 0-8053-7146-X. OCLC 71890442.
- Colinvaux, Paul (1979). *Why Big Fierce Animals are Rare: An Ecologist's Perspective* (reissue ed.). Princeton University Press. ISBN 0691023646. OCLC 10081738 24132192.
- Hoagland, Mahlon (2001). *The Way Life Works* (reprint ed.). Jones and Bartlett Publishers inc. ISBN 076371688X. OCLC 223090105 45487537.
- Janovy, John Jr. (2004). *On Becoming a Biologist* (2nd ed.). Bison Books. ISBN 0803276206. OCLC 55138571 56964280.
- Johnson, George B. (2005). *Biology, Visualizing Life*. Holt, Rinehart, and Winston. ISBN 0-03-016723-X. OCLC 36306648.
- Tobin, Allan; Dusheck, Jennie (2005). *Asking About Life* (3rd ed.). Belmont, CA: Wadsworth. ISBN 0-534-40653X.

External links

- Biology (http://www.dmoz.org/Science/Biology/) at the Open Directory Project
- OSU's Phylocode (http://www.ohiou.edu/phylocode/index.html)
- Biology Online – Wiki Dictionary (http://www.biology-online.org/dictionary/Main_Page)
- MIT video lecture series on biology (http://ocw.mit.edu/OcwWeb/Biology/7-012Fall-2004/VideoLectures/)
- Biology and Bioethics (http://www.bioeticaunbosque.edu.co/english/).
- Biological Systems (https://inlportal.inl.gov/portal/server.pt?open=514&objID=2622&parentname=CommunityPage&parentid=7&mode=2&in_hi_userid=200&cached=true) – Idaho National Laboratory
- *The Tree of Life* (http://tolweb.org/tree/phylogeny.html): A multi-authored, distributed Internet project containing information about phylogeny and biodiversity.
- Using the Biological Literature Web Resources (http://www.library.illinois.edu/bix/biologicalliterature/)

Journal links

- PLos Biology (http://biology.plosjournals.org/perlserv/?request=index-html&issn=1545-7885) A peer-reviewed, open-access journal published by the Public Library of Science
- Current Biology (http://www.cell.com/current-biology/) General journal publishing original research from all areas of biology
- Biology Letters (http://rsbl.royalsocietypublishing.org/) A high-impact Royal Society journal publishing peer-reviewed Biology papers of general interest
- Science Magazine (http://www.sciencemag.org/collections/subject/) Internationally Renowned AAAS Science Publication – See Sections of the Life Sciences
- International Journal of Biological Sciences (http://www.biolsci.org) A biological journal publishing significant peer-reviewed scientific papers
- [[Perspectives in Biology and Medicine (http://www.press.jhu.edu/journals/perspectives_in_biology_and_medicine/index.html)] An interdisciplinary scholarly journal publishing essays of broad relevance
- Life Science Log (http://www.lifesciencelog.com/)

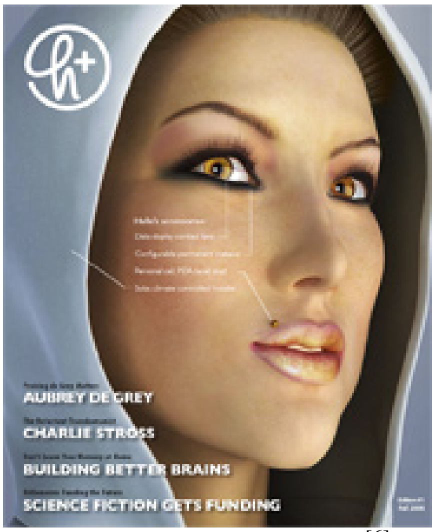
Transhumanism

Transhumanism, abbreviated as **H+** or **h+**, is an international intellectual and cultural movement that affirms the possibility and desirability of fundamentally transforming the human condition by developing and making widely available technologies to eliminate aging and to greatly enhance human intellectual, physical, and psychological capacities.[1] Transhumanist thinkers study the potential benefits and dangers of emerging technologies that could overcome fundamental human limitations, as well as study the ethical matters involved in developing and using such technologies. They predict that human beings may eventually be able to transform themselves into beings with such greatly expanded abilities as to merit the label "posthuman".[1]

The contemporary meaning of the term *transhumanism* was foreshadowed by one of the first professors of futurology, FM-2030, who taught "new concepts of the Human" at The New School of New York City in the 1960s, when he began to identify people who adopt technologies, lifestyles and worldviews *transitional* to "posthumanity" as "transhuman".[2] This hypothesis would lay the intellectual groundwork for the British philosopher Max More to begin articulating the principles of transhumanism as a futurist philosophy in 1990, and organizing in California an intelligentsia that has since grown into the worldwide transhumanist movement.[2][3]

Influenced by seminal works of science fiction, the transhumanist vision of a transformed future humanity has attracted many supporters and detractors from a wide range of perspectives.[2] Transhumanism has been characterized by one critic, Francis Fukuyama, as among the world's most dangerous ideas,[4], to which Ronald Bailey countered that it is rather the "movement that epitomizes the most daring, courageous, imaginative, and idealistic aspirations of humanity".[5]

History



Cover of the first issue of h+ *Magazine* [6], a web-based quarterly publication that focuses on transhumanism, covering the scientific, technological, and cultural developments that are challenging and overcoming human limitations.

According to Nick Bostrom,[1] transcendentalist impulses have been expressed at least as far back as in the quest for immortality in the Epic of Gilgamesh, as well as historical quests for the Fountain of Youth, Elixir of Life, and other efforts to stave off aging and death.

There is debate within the transhumanist community about whether the philosophy of Friedrich Nietzsche can be considered an influence, despite its exaltation of the "overman", due to its emphasis on self-actualization rather than technological transformation.[1][7][8] Nikolai Fyodorov, a 19th-century Russian philosopher, advocated radical life extension, physical immortality and even resurrection of the dead using scientific methods.[9] In the 20th century, a direct and influential precursor to transhumanist concepts was geneticist J.B.S. Haldane's 1923 essay *Daedalus: Science and the Future*, which predicted that great benefits would come from applications of advanced sciences to human biology—and that every such advance would first appear to someone as blasphemy or perversion, "indecent and unnatural". J. D. Bernal speculated about space colonization, bionic implants, and cognitive enhancement, which have been common transhumanist themes since then.[1] Biologist Julian Huxley, brother of author Aldous Huxley (a childhood friend of Haldane's), appears to have been the first to use the actual word "transhumanism". Writing in 1957, he defined transhumanism as "man remaining man, but transcending himself, by realizing new possibilities of and for his human nature".[10] This definition differs, albeit not substantially, from the one commonly in use since the 1980s.

Computer scientist Marvin Minsky wrote on relationships between human and artificial intelligence beginning in the 1960s.[11] Over the succeeding decades, this field continued to generate influential thinkers, such as Hans Moravec and Raymond Kurzweil, who oscillated between the technical arena and futuristic speculations in the transhumanist vein.[12][13] The coalescence of an identifiable transhumanist movement began in the last decades of the 20th century. In 1966, FM-2030 (formerly F.M. Esfandiary), a futurist who taught "new concepts of the Human" at The New School in New York City, began to identify people who adopt technologies, lifestyles and world views transitional to "posthumanity" as "transhuman".[14] In 1972, Robert Ettinger contributed to the conceptualization of "transhumanity" in his book *Man into Superman*.[15][16] FM-2030 published the *Upwingers Manifesto* in 1973.[17]

The first self-described transhumanists met formally in the early 1980s at the University of California, Los Angeles, which became the main center of transhumanist thought. Here, FM-2030 lectured on his "Third Way" futurist ideology. At the EZTV Media venue frequented by transhumanists and other futurists, Natasha Vita-More presented *Breaking Away*, her 1980 experimental film with the theme of humans breaking away from their biological limitations and the Earth's gravity as they head into space.[18][19] FM-2030 and Vita-More soon began holding gatherings for transhumanists in Los Angeles, which included students from FM-2030's courses and audiences from Vita-More's artistic productions. In 1982, Vita-More authored the *Transhumanist Arts Statement*,[20] and, six years later, produced the cable TV show *TransCentury Update* on transhumanity, a program which reached over 100,000 viewers.

In 1986, Eric Drexler published *Engines of Creation: The Coming Era of Nanotechnology,*[21] which discussed the prospects for nanotechnology and molecular assemblers, and founded the Foresight Institute. As the first non-profit organization to research, advocate for, and perform cryonics, the Southern California offices of the Alcor Life Extension Foundation became a center for futurists. In 1988, the first issue of *Extropy Magazine* was published by Max More and Tom Morrow. In 1990, More, a strategic philosopher, created his own particular transhumanist doctrine, which took the form of the *Principles of Extropy*,[22] and laid the foundation of modern transhumanism by giving it a new definition:[23]

> Transhumanism is a class of philosophies that seek to guide us towards a posthuman condition. Transhumanism shares many elements of humanism, including a respect for reason and science, a commitment to progress, and a valuing of human (or transhuman) existence in this life. [...] Transhumanism differs from humanism in recognizing and anticipating the radical alterations in the nature and possibilities of our lives resulting from various sciences and technologies [...].

In 1992, More and Morrow founded the Extropy Institute, a catalyst for networking futurists and brainstorming new memeplexes by organizing a series of conferences and, more importantly, providing a mailing list, which exposed many to transhumanist views for the first time during the rise of cyberculture and the cyberdelic counterculture. In 1998, philosophers Nick Bostrom and David Pearce founded the World Transhumanist Association (WTA), an international non-governmental organization working toward the recognition of transhumanism as a legitimate subject of scientific inquiry and public policy.[24] In 2002, the WTA modified and adopted *The Transhumanist Declaration*.[25] *The Transhumanist FAQ*, prepared by the WTA, gave two formal definitions for transhumanism:[26]

1. The intellectual and cultural movement that affirms the possibility and desirability of fundamentally improving the human condition through applied reason, especially by developing and making widely available technologies to eliminate aging and to greatly enhance human intellectual, physical, and psychological capacities.
2. The study of the ramifications, promises, and potential dangers of technologies that will enable us to overcome fundamental human limitations, and the related study of the ethical matters involved in developing and using such technologies.

A number of similar definitions have been collected by Anders Sandberg, an academic and prominent transhumanist.[27]

In possible contrast with other transhumanist organizations, WTA officials considered that social forces could undermine their futurist visions and needed to be addressed.[2] A particular concern is the equal access to human enhancement technologies across classes and borders.[28] In 2006, a political struggle within the transhumanist movement between the libertarian right and the liberal left resulted in a more centre-leftward positioning of the WTA under its former executive director James Hughes.[28][29] In 2006, the board of directors of the Extropy Institute ceased operations of the organization, stating that its mission was "essentially completed".[30] This left the World Transhumanist Association as the leading international transhumanist organization. In 2008, as part of a rebranding effort, the WTA changed its name to "Humanity+" in order to project a more humane image.[31] Humanity Plus and Betterhumans publish *h+ Magazine*, a periodical edited by R. U. Sirius which disseminates transhumanist news and ideas.[32][33]

The first transhumanist elected member of a Parliament is Giuseppe Vatinno, in Italy.[34]

Theory

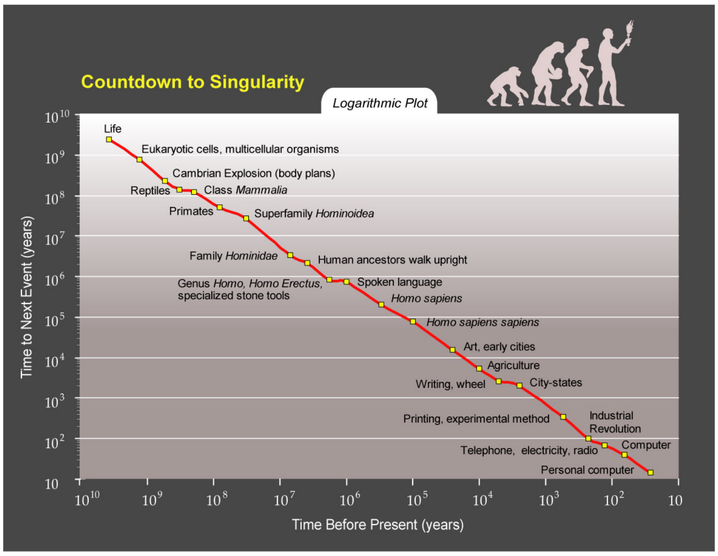
It is a matter of debate whether transhumanism is a branch of "posthumanism" and how posthumanism should be conceptualised with regard to transhumanism. The latter is often referred to as a variant or activist form of posthumanism by its conservative,[4] Christian[35] and progressive[36][37] critics. A common feature of transhumanism and philosophical posthumanism is the future vision of a new intelligent species, into which humanity will evolve, which will supplement humanity or supersede it. Transhumanism stresses the evolutionary perspective, including sometimes the creation of a highly intelligent animal species by way of cognitive enhancement (i.e. biological uplift),[2] but clings to a "posthuman future" as the final goal of participant evolution.[38]

Nevertheless, the idea of creating intelligent artificial beings, proposed, for example, by roboticist Hans Moravec, has influenced transhumanism.[12] Moravec's ideas and transhumanism have also been characterised as a "complacent" or "apocalyptic" variant of posthumanism and contrasted with "cultural posthumanism" in humanities and the arts.[39] While such a "cultural posthumanism" would offer resources for rethinking the relations of humans and increasingly sophisticated machines, transhumanism and similar posthumanisms are, in this view, not abandoning obsolete concepts of the "autonomous liberal subject" but are expanding its "prerogatives" into the realm of the posthuman.[40] Transhumanist self-characterisations as a continuation of humanism and Enlightenment thinking correspond with this view.

Some secular humanists conceive transhumanism as an offspring of the humanist freethought movement and argue that transhumanists differ from the humanist mainstream by having a specific focus on technological approaches to resolving human concerns (i.e. technocentrism) and on the issue of mortality.[41] However, other progressives have argued that posthumanism, whether it be its philosophical or activist forms, amount to a shift away from concerns about social justice, from the reform of human institutions and from other Enlightenment preoccupations, toward narcissistic longings for a transcendence of the human body in quest of more exquisite ways of being.[42] In this view, transhumanism is abandoning the goals of humanism, the Enlightenment, and progressive politics.

Aims

While many transhumanist theorists and advocates seek to apply reason, science and technology for the purposes of reducing poverty, disease, disability, and malnutrition around the globe,[26] transhumanism is distinctive in its particular focus on the applications of technologies to the improvement of human bodies at the individual level. Many transhumanists actively assess the potential for future technologies and innovative social systems to improve the quality of all life, while seeking to make the material reality of the human condition fulfill the promise of legal and political equality by eliminating congenital mental and physical barriers.



"Countdown to Singularity" (Raymond Kurzweil)

Transhumanist philosophers argue that there not only exists a perfectionist ethical imperative for humans to strive for progress and improvement of the human condition but that it is possible and desirable for humanity to enter a transhuman phase of existence, in which humans are in control of their own evolution. In such a phase, natural evolution would be replaced with deliberate change.

Some theorists, such as Raymond Kurzweil, think that the pace of technological innovation is accelerating and that the next 50 years may yield not only radical technological advances but possibly a technological singularity, which may fundamentally change the nature of human beings.[43] Transhumanists who foresee this massive technological change generally maintain that it is desirable. However, some are also concerned with the possible dangers of extremely rapid technological change and propose options for ensuring that advanced technology is used responsibly. For example, Bostrom has written extensively on existential risks to humanity's future welfare, including risks that could be created by emerging technologies.[44]

Ethics

Transhumanists engage in interdisciplinary approaches to understanding and evaluating possibilities for overcoming biological limitations by drawing on futurology and various fields of ethics. Unlike many philosophers, social critics, and activists who place a moral value on preservation of natural systems, transhumanists see the very concept of the specifically "natural" as problematically nebulous at best, and an obstacle to progress at worst.[45] In keeping with this, many prominent transhumanist advocates refer to transhumanism's critics on the political right and left jointly as "bioconservatives" or "bioluddites", the latter term alluding to the 19th century anti-industrialisation social movement that opposed the replacement of human manual labourers by machines.[46]

Currents

There is a variety of opinion within transhumanist thought. Many of the leading transhumanist thinkers hold views that are under constant revision and development.[47] Some distinctive currents of transhumanism are identified and listed here in alphabetical order:

- Abolitionism, an ethical ideology based upon a perceived obligation to use technology to eliminate involuntary suffering in all sentient life.[48]
- Democratic transhumanism, a political ideology synthesizing liberal democracy, social democracy, radical democracy and transhumanism.[49]
- Extropianism, an early school of transhumanist thought characterized by a set of principles advocating a proactive approach to human evolution.[23]
- Immortalism, a moral ideology based upon the belief that technological immortality is possible and desirable, and advocating research and development to ensure its realization.[50]
- Libertarian transhumanism, a political ideology synthesizing right-libertarianism and transhumanism.[46]
- Postgenderism, a social philosophy which seeks the voluntary elimination of gender in the human species through the application of advanced biotechnology and assisted reproductive technologies.[51]
- Singularitarianism, a moral ideology based upon the belief that a technological singularity is possible, and advocating deliberate action to effect it and ensure its safety.[43]
- Technogaianism, an ecological ideology based upon the belief that emerging technologies can help restore Earth's environment, and that developing safe, clean, alternative technology should therefore be an important goal of environmentalists.[49]

Spirituality

Although some transhumanists report having religious or spiritual views, they are for the most part atheists, agnostics or secular humanists.[24] Despite the prevailing secular attitude, some transhumanists pursue hopes traditionally espoused by religions, such as "immortality",[50] while several controversial new religious movements, originating in the late 20th century, have explicitly embraced transhumanist goals of transforming the human condition by applying technology to the alteration of the mind and body, such as Raëlism.[52] However, most thinkers associated with the transhumanist movement focus on the practical goals of using technology to help achieve longer and healthier lives; while speculating that future understanding of neurotheology and the application of neurotechnology will enable humans to gain greater control of altered states of consciousness, which were commonly interpreted as "spiritual experiences", and thus achieve more profound self-knowledge.[53]

Many transhumanists believe in the compatibility of human minds with computer hardware, with the theoretical implication that human consciousness may someday be transferred to alternative media, a speculative technique commonly known as "mind uploading".[54] One extreme formulation of this idea, which some transhumanists are interested in, is the proposal of the "Omega Point" by Christian cosmologist Frank Tipler. Drawing upon ideas in digitalism, Tipler has advanced the notion that the collapse of the Universe billions of years hence could create the conditions for the perpetuation of humanity in a simulated reality within a megacomputer, and thus achieve a form of "posthuman godhood". Tipler's thought was inspired by the writings of Pierre Teilhard de Chardin, a paleontologist and Jesuit theologian who saw an evolutionary telos in the development of an encompassing noosphere, a global consciousness.[55][56][57]

Viewed from the perspective of some Christian fundamentalists, the idea of mind uploading is asserted to represent a denigration of the human body characteristic of gnostic belief.[58] Transhumanism and its presumed intellectual progenitors have also been described as neo-gnostic by non-Christian and secular commentators.[59][60]

The first dialogue between transhumanism and faith was a one day conference held at the University of Toronto in 2004.[61] Religious critics alone faulted the philosophy of transhumanism as offering no eternal truths nor a relationship with the divine. They commented that a philosophy bereft of these beliefs leaves humanity adrift in a

foggy sea of postmodern cynicism and anomie. Transhumanists responded that such criticisms reflect a failure to look at the actual content of the transhumanist philosophy, which far from being cynical, is rooted in optimistic, idealistic attitudes that trace back to the Enlightenment.[62] Following this dialogue, William Sims Bainbridge, a sociologist of religion, conducted a pilot study, published in the Journal of Evolution and Technology, suggesting that religious attitudes were negatively correlated with acceptance of transhumanist ideas, and indicating that individuals with highly religious worldviews tended to perceive transhumanism as being a direct, competitive (though ultimately futile) affront to their spiritual beliefs.[63]

Since 2009, the American Academy of Religion holds a "Transhumanism and Religion" consultation during its annual meeting where scholars in the field of religious studies seek to identify and critically evaluate any implicit religious beliefs that might underlie key transhumanist claims and assumptions; consider how transhumanism challenges religious traditions to develop their own ideas of the human future, in particular the prospect of human transformation, whether by technological or other means; and provide critical and constructive assessments of an envisioned future that place greater confidence in nanotechnology, robotics, and information technology to achieve virtual immortality and create a superior posthuman species.[64]

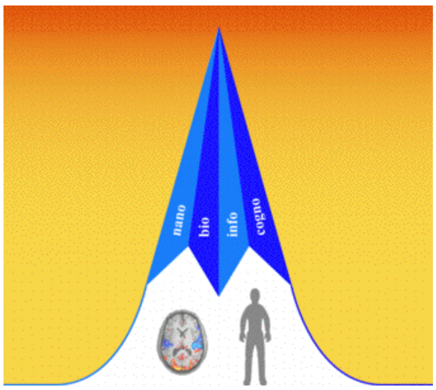
Practice

While some transhumanists take an abstract and theoretical approach to the perceived benefits of emerging technologies, others have offered specific proposals for modifications to the human body, including heritable ones. Transhumanists are often concerned with methods of enhancing the human nervous system. Though some propose modification of the peripheral nervous system, the brain is considered the common denominator of personhood and is thus a primary focus of transhumanist ambitions.[65]

As proponents of self-improvement and body modification, transhumanists tend to use existing technologies and techniques that supposedly improve cognitive and physical performance, while engaging in routines and lifestyles designed to improve health and longevity.[66] Depending on their age, some transhumanists express concern that they will not live to reap the benefits of future technologies. However, many have a great interest in life extension strategies, and in funding research in cryonics in order to make the latter a viable option of last resort rather than remaining an unproven method.[67] Regional and global transhumanist networks and communities with a range of objectives exist to provide support and forums for discussion and collaborative projects.

Technologies of interest

Transhumanists support the emergence and convergence of technologies such as nanotechnology, biotechnology, information technology and cognitive science (NBIC), and hypothetical future technologies such as simulated reality, artificial intelligence, superintelligence, mind uploading, chemical brain preservation, and cryonics. They believe that humans can and should use these technologies to become more than human.[69] They therefore support the recognition and/or protection of cognitive liberty, morphological freedom, and procreative liberty as civil liberties, so as to guarantee individuals the choice of using human enhancement technologies on themselves and their children.[70] Some speculate that human enhancement techniques and other emerging technologies may facilitate more radical human enhancement no later than the midpoint of the 21st century.[43]



Converging Technologies, a 2002 report exploring the potential for synergy among nano-, bio-, info- and cogno-technologies, has become a landmark in near-future technological speculation.[68]

Some reports on the converging technologies and NBIC concepts have criticised their transhumanist orientation and alleged science fictional character.[71] At the same time, research on brain and body alteration technologies has accelerated under the sponsorship of the US Department of Defense, which is interested in the battlefield advantages they would provide to the "supersoldiers" of the United States and its allies.[72] There has already been a brain research program to "extend the ability to manage information" while military scientists are now looking at stretching the human capacity for combat to a maximum 168 hours without sleep.[73]

Arts and culture

Transhumanist themes have become increasingly prominent in various literary forms during the period in which the movement itself has emerged. Contemporary science fiction often contains positive renditions of technologically enhanced human life, set in utopian (especially techno-utopian) societies. However, science fiction's depictions of enhanced humans or other posthuman beings frequently come with a cautionary twist. The more pessimistic scenarios include many horrific or dystopian tales of human bioengineering gone wrong. In the decades immediately before transhumanism emerged as an explicit movement, many transhumanist concepts and themes began appearing in the speculative fiction of authors of the Golden Age of Science Fiction such as Robert A. Heinlein (Lazarus Long series, 1941–87), A. E. van Vogt (*Slan*, 1946), Isaac Asimov (*I, Robot*, 1950), Arthur C. Clarke (*Childhood's End*, 1953) and Stanisław Lem (*Cyberiad*, 1967).[2]

The cyberpunk genre, exemplified by William Gibson's *Neuromancer* (1984) and Bruce Sterling's *Schismatrix* (1985), has particularly been concerned with the modification of human bodies. Other novels dealing with transhumanist themes that have stimulated broad discussion of these issues include *Blood Music* (1985) by Greg Bear, *The Xenogenesis Trilogy* (1987–1989) by Octavia Butler; *The Beggar's Trilogy* (1990–94) by Nancy Kress; much of Greg Egan's work since the early 1990s, such as *Permutation City* (1994) and *Diaspora* (1997); The Culture series of Iain M. Banks; *The Bohr Maker* (1995) by Linda Nagata; *Altered Carbon* (2002) by Richard K Morgan; *Oryx and Crake* (2003) by Margaret Atwood; *The Elementary Particles* (Eng. trans. 2001) and *The Possibility of an Island* (Eng. trans. 2006) by Michel Houellebecq; *Mindscan* (2005) by Robert J. Sawyer; the *Commonwealth Saga* (2002–10) by Peter F. Hamilton and *Glasshouse* (2005) by Charles Stross. Some (but not all) of these works are considered part of the cyberpunk genre or its postcyberpunk offshoot.

> “Your mind is software. Program it.
> Your body is a shell. Change it.
> Death is a disease. Cure it.
> Extinction is approaching. Fight it.”
>
> —Eclipse Phase

Fictional transhumanist scenarios have also become popular in other media during the late twentieth and early twenty first centuries. Such treatments are found in comic books (*Captain America*, 1941; *Transmetropolitan*, 1997; *The Surrogates*, 2006), films (*2001: A Space Odyssey*, 1968; *Blade Runner*, 1982; *Gattaca*, 1997; television series (the Cybermen of *Doctor Who*, 1966; the Borg of *Star Trek: The Next Generation*, 1989; manga and anime (*Galaxy Express 999*, 1978; *Appleseed*, 1985; *Ghost in the Shell*, 1989; *Neon Genesis Evangelion*, 1995; and the *Gundam* metaseries, 1979), video games (*Metal Gear Solid*, 1998; *Deus Ex*, 2000; *BioShock*, 2007; *Crysis 2*, 2011;*Deus Ex: Human Revolution*, 2011[74]), and role-playing games.

In addition to the work of Natasha Vita-More, curator of the Transhumanist Arts & Culture center, transhumanist themes appear in the visual and performing arts.[75] Carnal Art, a form of sculpture originated by the French artist Orlan, uses the body as its medium and plastic surgery as its method.[76] Commentators have pointed to American performer Michael Jackson as having used technologies such as plastic surgery, skin-lightening drugs and hyperbaric oxygen therapy over the course of his career, with the effect of transforming his artistic persona so as to blur identifiers of gender, race and age.[77] Other artists whose work coincided with the emergence and flourishing of

transhumanism and who explored themes related to the transformation of the body are the Yugoslavian performance artist Marina Abramovic and the American media artist Matthew Barney. A 2005 show, *Becoming Animal*, at the Massachusetts Museum of Contemporary Art, presented exhibits by twelve artists whose work concerns the effects of technology in erasing boundaries between the human and non-human.

Debate

Some elements of transhumanist thought and research are considered by critics to be within the realm of fringe science because it departs significantly from the mainstream.[78] The very notion and prospect of human enhancement and related issues also arouse public controversy.[79] Criticisms of transhumanism and its proposals take two main forms: those objecting to the likelihood of transhumanist goals being achieved (practical criticisms); and those objecting to the moral principles or world view sustaining transhumanist proposals or underlying transhumanism itself (ethical criticisms). However, these two strains sometimes converge and overlap, particularly when considering the ethics of changing human biology in the face of incomplete knowledge.

Critics or opponents often see transhumanists' goals as posing threats to human values.[80] Some also argue that strong advocacy of a transhumanist approach to improving the human condition might divert attention and resources from social solutions.[2] As most transhumanists support non-technological changes to society, such as the spread of civil rights and civil liberties, and most critics of transhumanism support technological advances in areas such as communications and health care, the difference is often a matter of emphasis. Sometimes, however, there are strong disagreements about the very principles involved, with divergent views on humanity, human nature, and the morality of transhumanist aspirations.[2] At least one public interest organization, the U.S.-based Center for Genetics and Society, was formed, in 2001, with the specific goal of opposing transhumanist agendas that involve transgenerational modification of human biology, such as full-term human cloning and germinal choice technology. The Institute on Biotechnology and the Human Future of the Chicago-Kent College of Law critically scrutinizes proposed applications of genetic and nanotechnologies to human biology in an academic setting.

Some of the most widely known critiques of the transhumanist program refer to novels and fictional films. These works of art, despite presenting imagined worlds rather than philosophical analyses, are used as touchstones for some of the more formal arguments.[2]

Feasibility

In a 1992 book, sociologist Max Dublin pointed to many past failed predictions of technological progress and argued that modern futurist predictions would prove similarly inaccurate. He also objected to what he saw as scientism, fanaticism, and nihilism by a few in advancing transhumanist causes, and said that historical parallels exised to millenarian religions and Communist doctrines.[81]

Although generally sympathetic to transhumanism, public health professor Gregory Stock is skeptical of the technical feasibility and mass appeal of the cyborgization of humanity predicted by Raymond Kurzweil, Hans Moravec and Kevin Warwick. He said that throughout the 21st century, many humans would find themselves deeply integrated into systems of machines, but would remain biological. Primary changes to their own form and character would arise not from cyberware but from the direct manipulation of their genetics, metabolism, and biochemistry.[82]

Those thinkers who defend the likelihood of accelerating change point to a past pattern of exponential increases in humanity's technological capacities. Kurzweil developed this position in his 2005 book, *The Singularity Is Near*.

Hubris

It has been argued that in transhumanist thought humans attempt to substitute themselves for God. This approach is exemplified by the 2002 Vatican statement *Communion and Stewardship: Human Persons Created in the Image of God,*[83] in which it is stated that, "Changing the genetic identity of man as a human person through the production of an infrahuman being is radically immoral", implying, as it would, that "man has full right of disposal over his own biological nature". At the same time, this statement argues that creation of a superhuman or spiritually superior being is "unthinkable", since true improvement can come only through religious experience and "realizing more fully the image of God". Christian theologians and lay activists of several churches and denominations have expressed similar objections to transhumanism and claimed that Christians already enjoy, however post mortem, what radical transhumanism promises such as indefinite life extension or the abolition of suffering. In this view, transhumanism is just another representative of the long line of utopian movements which seek to immanentize the eschaton i.e. try to create "heaven on earth".[84][85]

The biocomplexity spiral is a depiction of the multileveled complexity of organisms in their environments, which is seen by many critics as the ultimate obstacle to transhumanist ambition.

Another critique is aimed mainly at "algeny", which Jeremy Rifkin defined as "the upgrading of existing organisms and the design of wholly new ones with the intent of 'perfecting' their performance",[86] and, more specifically, attempts to pursue transhumanist goals by way of genetically modifying human embryos in order to create "designer babies". It emphasizes the issue of biocomplexity and the unpredictability of attempts to guide the development of products of biological evolution. This argument, elaborated in particular by the biologist Stuart Newman, is based on the recognition that the cloning and germline genetic engineering of animals are error-prone and inherently disruptive of embryonic development. Accordingly, so it is argued, it would create unacceptable risks to use such methods on human embryos. Performing experiments, particularly ones with permanent biological consequences, on developing humans, would thus be in violation of accepted principles governing research on human subjects (see the 1964 Declaration of Helsinki). Moreover, because improvements in experimental outcomes in one species are not automatically transferable to a new species without further experimentation, there is claimed to be no ethical route to genetic manipulation of humans at early developmental stages.[87]

As a practical matter, however, international protocols on human subject research may not present a legal obstacle to attempts by transhumanists and others to improve their offspring by germinal choice technology. According to legal scholar Kirsten Rabe Smolensky, existing laws would protect parents who choose to enhance their child's genome from future liability arising from adverse outcomes of the procedure.[88]

Religious thinkers allied with transhumanist goals, such as the theologians Ronald Cole-Turner and Ted Peters, reject the first argument, holding that the doctrine of "co-creation" provides an obligation to use genetic engineering to improve human biology.[89][90]

Transhumanists and other supporters of human genetic engineering do not dismiss the second argument out of hand, insofar as there is a high degree of uncertainty about the likely outcomes of genetic modification experiments in humans. However, bioethicist James Hughes suggests that one possible ethical route to the genetic manipulation of humans at early developmental stages is the building of computer models of the human genome, the proteins it specifies, and the tissue engineering he argues that it also codes for. With the exponential progress in bioinformatics, Hughes believes that a virtual model of genetic expression in the human body will not be far behind and that it will soon be possible to accelerate approval of genetic modifications by simulating their effects on virtual humans.[2] Public health professor Gregory Stock points to artificial chromosomes as an alleged safer alternative to existing genetic engineering techniques.[82] Transhumanists therefore argue that parents have a moral responsibility called

procreative beneficence to make use of these methods, if and when they are shown to be reasonably safe and effective, to have the healthiest children possible. They add that this responsibility is a moral judgment best left to individual conscience rather than imposed by law, in all but extreme cases. In this context, the emphasis on freedom of choice is called procreative liberty.[2]

Contempt for the flesh

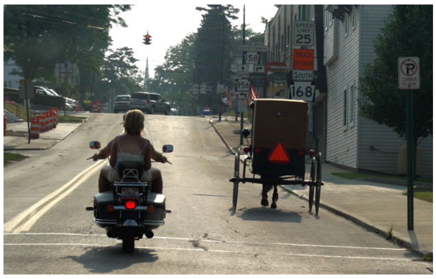
Philosopher Mary Midgley, in her 1992 book *Science as Salvation*, traces the notion of achieving immortality by transcendence of the material human body (echoed in the transhumanist tenet of mind uploading) to a group of male scientific thinkers of the early 20th century, including J.B.S. Haldane and members of his circle. She characterizes these ideas as "quasi-scientific dreams and prophesies" involving visions of escape from the body coupled with "self-indulgent, uncontrolled power-fantasies". Her argument focuses on what she perceives as the pseudoscientific speculations and irrational, fear-of-death-driven fantasies of these thinkers, their disregard for laymen, and the remoteness of their eschatological visions.[91]

What is perceived as contempt for the flesh in the writings of Marvin Minsky, Hans Moravec, and some transhumanists, has also been the target of other critics for what they claim to be an instrumental conception of the human body.[40] Reflecting a strain of feminist criticism of the transhumanist program, philosopher Susan Bordo points to "contemporary obsessions with slenderness, youth, and physical perfection", which she sees as affecting both men and women, but in distinct ways, as "the logical (if extreme) manifestations of anxieties and fantasies fostered by our culture."[92] Some critics question other social implications of the movement's focus on body modification. Political scientist Klaus-Gerd Giesen, in particular, has asserted that transhumanism's concentration on altering the human body represents the logical yet tragic consequence of atomized individualism and body commodification within a consumer culture.[59]

Nick Bostrom asserts that the desire to regain youth, specifically, and transcend the natural limitations of the human body, in general, is pan-cultural and pan-historical, and is therefore not uniquely tied to the culture of the 20th century. He argues that the transhumanist program is an attempt to channel that desire into a scientific project on par with the Human Genome Project and achieve humanity's oldest hope, rather than a puerile fantasy or social trend.[1]

Trivialization of human identity

In his 2003 book *Enough: Staying Human in an Engineered Age*, environmental ethicist Bill McKibben argued at length against many of the technologies that are postulated or supported by transhumanists, including germinal choice technology, nanomedicine and life extension strategies. He claims that it would be morally wrong for humans to tamper with fundamental aspects of themselves (or their children) in an attempt to overcome universal human limitations, such as vulnerability to aging, maximum life span, and biological constraints on physical and cognitive ability. Attempts to "improve" themselves through such manipulation would remove limitations that provide a necessary context for the experience of meaningful human choice. He claims that human lives would no longer seem meaningful in a world where such limitations could be overcome technologically. Even the goal of using germinal choice technology for clearly *therapeutic* purposes should be relinquished, since it would inevitably produce temptations to tamper with such things as cognitive capacities. He argues that it is possible for societies to benefit from renouncing particular technologies, using as examples Ming China, Tokugawa Japan and the contemporary Amish.[94]



In the US, the Amish are a religious group probably most known for their avoidance of certain modern technologies. Transhumanists draw a parallel by arguing that in the near-future there will probably be "Humanish", people who choose to "stay human" by not adopting human enhancement technologies, whose choice they believe must be respected and protected.[93]

Transhumanists and other supporters of technological alteration of human biology, such as science journalist Ronald Bailey, reject as extremely subjective the claim that life would be experienced as meaningless if some human limitations are overcome with enhancement technologies. They argue that these technologies will not remove the bulk of the individual and social challenges humanity faces. They suggest that a person with greater abilities would tackle more advanced and difficult projects and continue to find meaning in the struggle to achieve excellence. Bailey also claims that McKibben's historical examples are flawed, and support different conclusions when studied more closely.[95] For example, few groups are more cautious than the Amish about embracing new technologies, but though they shun television and use horses and buggies, some are welcoming the possibilities of gene therapy since inbreeding has afflicted them with a number of rare genetic diseases.[82]

Genetic divide

Some critics of libertarian transhumanism have focused on its likely socioeconomic consequences in societies in which divisions between rich and poor are on the rise. Bill McKibben, for example, suggests that emerging human enhancement technologies would be disproportionately available to those with greater financial resources, thereby exacerbating the gap between rich and poor and creating a "genetic divide".[94] Lee M. Silver, a biologist and science writer who coined the term "reprogenetics" and supports its applications, has nonetheless expressed concern that these methods could create a two-tiered society of genetically engineered "haves" and "have nots" if social democratic reforms lag behind implementation of enhancement technologies.[96] Critics who make these arguments do not thereby necessarily accept the transhumanist assumption that human enhancement is a positive value; in their view, it should be discouraged, or even banned, because it could confer additional power upon the already powerful. The 1997 film *Gattaca*'s depiction of a dystopian society in which one's social class depends entirely on genetic modifications is often cited by critics in support of these views.[2]

These criticisms are also voiced by non-libertarian transhumanist advocates, especially self-described democratic transhumanists, who believe that the majority of current or future social and environmental issues (such as unemployment and resource depletion) need to be addressed by a combination of political and technological solutions (such as a guaranteed minimum income and alternative technology). Therefore, on the specific issue of an emerging genetic divide due to unequal access to human enhancement technologies, bioethicist James Hughes, in his 2004 book *Citizen Cyborg: Why Democratic Societies Must Respond to the Redesigned Human of the Future*, argues that progressives or, more precisely, techno-progressives must articulate and implement public policies (such as a universal health care voucher system that covers human enhancement technologies) in order to attenuate this problem as much as possible, rather than trying to ban human enhancement technologies. The latter, he argues, might actually worsen the problem by making these technologies unsafe or available only to the wealthy on the local black market or in countries where such a ban is not enforced.[2]

Threats to morality and democracy

Various arguments have been made to the effect that a society that adopts human enhancement technologies may come to resemble the dystopia depicted in the 1932 novel *Brave New World* by Aldous Huxley. Sometimes, as in the writings of Leon Kass, the fear is that various institutions and practices judged as fundamental to civilized society would be damaged or destroyed.[97] In his 2002 book *Our Posthuman Future* and in a 2004 *Foreign Policy* magazine article, political economist and philosopher Francis Fukuyama designates transhumanism the world's most dangerous idea because he believes that it may undermine the egalitarian ideals of democracy in general and liberal democracy in particular, through a fundamental alteration of "human nature".[4] Social philosopher Jürgen Habermas makes a similar argument in his 2003 book *The Future of Human Nature*, in which he asserts that moral autonomy depends on not being subject to another's unilaterally imposed specifications. Habermas thus suggests that the human "species ethic" would be undermined by embryo-stage genetic alteration.[98] Critics such as Kass, Fukuyama, and a variety of Christian authors hold that attempts to significantly alter human biology are not only inherently immoral but also threaten the social order. Alternatively, they argue that implementation of such technologies would likely lead to the

"naturalizing" of social hierarchies or place new means of control in the hands of totalitarian regimes. The AI pioneer Joseph Weizenbaum criticizes what he sees as misanthropic tendencies in the language and ideas of some of his colleagues, in particular Marvin Minsky and Hans Moravec, which, by devaluing the human organism per se, promotes a discourse that enables divisive and undemocratic social policies.[99]

In a 2004 article in *Reason,* science journalist Ronald Bailey has contested the assertions of Fukuyama by arguing that political equality has never rested on the facts of human biology. He asserts that liberalism was founded not on the proposition of effective equality of human beings, or *de facto* equality, but on the assertion of an equality in political rights and before the law, or *de jure* equality. Bailey asserts that the products of genetic engineering may well ameliorate rather than exacerbate human inequality, giving to the many what were once the privileges of the few. Moreover, he argues, "the crowning achievement of the Enlightenment is the principle of tolerance". In fact, he argues, political liberalism is already the solution to the issue of human and posthuman rights since, in liberal societies, the law is meant to apply equally to all, no matter how rich or poor, powerful or powerless, educated or ignorant, enhanced or unenhanced.[5] Other thinkers who are sympathetic to transhumanist ideas, such as philosopher Russell Blackford, have also objected to the appeal to tradition, and what they see as alarmism, involved in *Brave New World*-type arguments.[100]

Dehumanization

Biopolitical activist Jeremy Rifkin and biologist Stuart Newman accept that biotechnology has the power to make profound changes in organismal identity. They argue against the genetic engineering of human beings, because they fear the blurring of the boundary between human and artifact.[87][101] Philosopher Keekok Lee sees such developments as part of an accelerating trend in modernization in which technology has been used to transform the "natural" into the "artifactual".[102] In the extreme, this could lead to the manufacturing and enslavement of "monsters" such as human clones, human-animal chimeras or bioroids, but even lesser dislocations of humans and non-humans from social and ecological systems are seen as problematic. The film *Blade Runner* (1982), the novels *The Boys From Brazil* (1978) and *The Island of Dr. Moreau* (1896) depict elements of such scenarios, but Mary Shelley's 1818 novel *Frankenstein* is most often alluded to by critics who suggest that biotechnologies could create objectified and socially unmoored people and subhumans. Such critics propose that strict measures be implemented to prevent what they portray as dehumanizing possibilities from ever happening, usually in the form of an international ban on human genetic engineering.[103]

Writing in *Reason* magazine, Ronald Bailey has accused opponents of research involving the modification of animals as indulging in alarmism when they speculate about the creation of subhuman creatures with human-like intelligence and brains resembling those of Homo sapiens. Bailey insists that the aim of conducting research on animals is simply to produce human health care benefits.[104]

A different response comes from transhumanist personhood theorists who object to what they characterize as the anthropomorphobia fueling some criticisms of this research, which science writer Isaac Asimov termed the "Frankenstein complex". They argue that, provided they are self-aware, human clones, human-animal chimeras and uplifted animals would all be unique persons deserving of respect, dignity, rights and citizenship. They conclude that the coming ethical issue is not the creation of so-called monsters but what they characterize as the "yuck factor" and "human-racism" that would judge and treat these creations as monstrous.[24][105]

Specter of coercive eugenicism

Some critics of transhumanism allege an ableist bias in the use of such concepts as "limitations", "enhancement" and "improvement". Some even see the old eugenics, social Darwinist and master race ideologies and programs of the past as warnings of what the promotion of eugenic enhancement technologies might unintentionally encourage. Some fear future "eugenics wars" as the worst-case scenario: the return of coercive state-sponsored genetic discrimination and human rights violations such as compulsory sterilization of persons with genetic defects, the

killing of the institutionalized and, specifically, segregation from, and genocide of, "races" perceived as inferior.[106] Health law professor George Annas and technology law professor Lori Andrews are prominent advocates of the position that the use of these technologies could lead to such human-posthuman caste warfare.[103][107]

For most of its history, eugenics has manifested itself as a movement to sterilize against their will the "genetically unfit" and encourage the selective breeding of the genetically fit. The major transhumanist organizations strongly condemn the coercion involved in such policies and reject the racist and classist assumptions on which they were based, along with the pseudoscientific notions that eugenic improvements could be accomplished in a practically meaningful time frame through selective human breeding.[107] Most transhumanist thinkers instead advocate a "new eugenics", a form of egalitarian liberal eugenics.[108] In their 2000 book *From Chance to Choice: Genetics and Justice*, (non-transhumanist) bioethicists Allen Buchanan, Dan Brock, Norman Daniels and Daniel Wikler have argued that liberal societies have an obligation to *encourage* as wide an adoption of eugenic enhancement technologies as possible (so long as such policies do not infringe on individuals' reproductive rights or exert undue pressures on prospective parents to use these technologies) in order to maximize public health and minimize the inequalities that may result from both natural genetic endowments and unequal access to genetic enhancements.[109] Most transhumanists holding similar views nonetheless distance themselves from the term "eugenics" (preferring "germinal choice" or "reprogenetics")[96] to avoid having their position confused with the discredited theories and practices of early-20th-century eugenic movements.[110]

Existential risks

Struck by a passage from Unabomber Theodore Kaczynski's anarcho-primitivist manifesto (quoted in Kurzweil's 1999 book, *The Age of Spiritual Machines*[13]), computer scientist Bill Joy became a notable critic of emerging technologies.[111] Joy's 2000 essay "Why the future doesn't need us" argues that human beings would likely guarantee their own extinction by developing the technologies favored by transhumanists. It invokes, for example, the "grey goo scenario" where out-of-control self-replicating nanorobots could consume entire ecosystems, resulting in global ecophagy.[112] Joy's warning was seized upon by appropriate technology organizations such as the ETC Group. Related notions were also voiced by self-described neo-luddite Kalle Lasn, a culture jammer who co-authored a 2001 spoof of Donna Haraway's 1985 *Cyborg Manifesto* as a critique of the techno-utopianism he interpreted it as promoting.[113] Lasn argues that high technology development should be completely relinquished since it inevitably serves corporate interests with devastating consequences on society and the environment.[114]

In his 2003 book *Our Final Hour*, British Astronomer Royal Martin Rees argues that advanced science and technology bring as much risk of disaster as opportunity for progress. However, Rees does not advocate a halt to scientific activity; he calls for tighter security and perhaps an end to traditional scientific openness.[115] Advocates of the precautionary principle, such as many in the environmental movement, also favor slow, careful progress or a halt in potentially dangerous areas. Some precautionists believe that artificial intelligence and robotics present possibilities of alternative forms of cognition that may threaten human life.[116] The *Terminator* franchise's doomsday depiction of the emergence of an A.I. that becomes a superintelligence - Skynet, a malignant computer network which initiates a nuclear war in order to exterminate the human species, has often been cited by some involved in this debate.[117]

Transhumanists do not necessarily rule out specific restrictions on emerging technologies so as to lessen the prospect of existential risk. Generally, however, they counter that proposals based on the precautionary principle are often unrealistic and sometimes even counter-productive, as opposed to the technogaian current of transhumanism which they claim is both realistic and productive. In his television series *Connections*, science historian James Burke dissects several views on technological change, including precautionism and the restriction of open inquiry. Burke questions the practicality of some of these views, but concludes that maintaining the *status quo* of inquiry and development poses hazards of its own, such as a disorienting rate of change and the depletion of our planet's resources. The common transhumanist position is a pragmatic one where society takes deliberate action to ensure the

early arrival of the benefits of safe, clean, alternative technology rather than fostering what it considers to be anti-scientific views and technophobia.[118]

One transhumanist solution proposed by Nick Bostrom is differential technological development, in which attempts would be made to influence the sequence in which technologies developed. In this approach, planners would strive to retard the development of possibly harmful technologies and their applications, while accelerating the development of likely beneficial technologies, especially those that offer protection against the harmful effects of others.[44] An argument for an "anti-progressionist and pessimistic version of transhumanism" has also been presented by Philippe Verdoux.[119]

References

[1] Bostrom, Nick (2005). "A history of transhumanist thought" (http://www.nickbostrom.com/papers/history.pdf) (PDF). *Journal of Evolution and Technology*. . Retrieved 2006-02-21.

[2] Hughes, James (2004). *Citizen Cyborg: Why Democratic Societies Must Respond to the Redesigned Human of the Future*. Westview Press. ISBN 0-8133-4198-1. OCLC 56632213.

[3] Gelles, David (2009). *Immortality 2.0: a silicon valley insider looks at California's Transhumanist movement* (http://ce399eugenics.wordpress.com/2010/06/19/immortality-2-0-a-silicon-valley-insider-looks-at-californias-transhumanist-movement/). . Retrieved 2012-04-14.

[4] Fukuyama, Francis (September/October 2004). "The world's most dangerous ideas: transhumanism" (http://www.foreignpolicy.com/articles/2004/09/01/transhumanism) (reprint). *Foreign Policy* (144): 42–43. . Retrieved 2008-11-14.

[5] Bailey, Ronald (2004-08-25). "Transhumanism: the most dangerous idea?" (http://web.archive.org/web/20060208032306/http://www.reason.com/rb/rb082504.shtml). *Reason*. Archived from the original (http://www.reason.com/rb/rb082504.shtml) on 2006-02-08. . Retrieved 2006-02-20.

[6] http://www.hplusmagazine.com/

[7] Sorgner, Stefan Lorenz (2009). / JET 20(1) March 2009 29-42 *Nietzsche, the Overhuman, and Transhumanism* (http://jetpress.org/v20/sorgner.htm). / JET 20(1) March 2009 29-42.

[8] Blackford, Russell (2010). *Editorial: Nietzsche and European Posthumanisms* (http://jetpress.org/v21/blackford.htm). .

[9] Berdayev, Nikolai (1915). *The Religion of Resuscitative Resurrection. "The Philosophy of the Common Task of N. F. Fedorov* (http://www.berdyaev.com/berdiaev/berd_lib/1915_186.html). . Retrieved 2008-01-04.

[10] Huxley, Julian (1957). *Transhumanism* (http://www.transhumanism.org/index.php/WTA/more/huxley/). . Retrieved 2006-02-24.

[11] Minsky, Marvin (1960). *Steps toward artificial intelligence* (http://web.media.mit.edu/~minsky/papers/steps.html). . Retrieved 2006-12-13.

[12] Moravec, Hans (1998). "When will computer hardware match the human brain?" (http://www.transhumanist.com/volume1/moravec.htm). *Journal of Evolution and Technology* **1**. . Retrieved 2006-06-23.

[13] Kurzweil, Raymond (1999). *The Age of Spiritual Machines*. Viking Adult. ISBN 0-670-88217-8. OCLC 224295064.

[14] FM-2030 (1989). *Are You a Transhuman?: Monitoring and Stimulating Your Personal Rate of Growth in a Rapidly Changing World*. Viking Adult. ISBN 0-446-38806-8. OCLC 18134470.

[15] Ettinger, Robert (1974). *Man into Superman* (http://www.cryonics.org/book2.html). Avon. ISBN 0-380-00047-4. .

[16] Gelles, David (2009-05-21). "Technocrats Lust For Eternal Life Through 'Reengineering' of Humanity" (http://www.informationliberation.com/?id=26779). informationliberation. . Retrieved 2009-05-24.

[17] FM-2030 (1973). *UpWingers: A Futurist Manifesto*. New York: John Day Co.. ISBN 0-381-98243-2; available as an eBook: FW00007527. OCLC 600299.

[18] "EZTV Media" (http://www.eztvmedia.com/his.html). . Retrieved 2006-05-01.

[19] Ed Regis (1990). *Great Mambo Chicken and the Transhuman Condition: Science Slightly Over the Edge*. Perseus Books.

[20] Vita-More, Natasha (1982; revised 2003). *Tranhumanist arts statement* (http://www.transhumanist.biz/transhumanistartsmanifesto.htm). . Retrieved 2006-02-16.

[21] Drexler 1986

[22] More, Max (1990–2003). *Principles of extropy* (http://extropy.org/principles.htm). . Retrieved 2006-02-16.

[23] More, Max (1990). *Transhumanism: a futurist philosophy* (http://www.maxmore.com/transhum.htm). . Retrieved 2005-11-14.

[24] Hughes, James (2005) (PDF). *Report on the 2005 interests and beliefs survey of the members of the World Transhumanist Association* (http://transhumanism.org/resources/survey2005.pdf). . Retrieved 2006-02-26.

[25] World Transhumanist Association (2002). *The Transhumanist Declaration* (http://web.archive.org/web/20060910010545/http://www.transhumanism.org/index.php/WTA/faq21/79/). Archived from the original (http://www.transhumanism.org/index.php/WTA/faq21/79/) on September 10, 2006. . Retrieved 2006-04-03.

[26] World Transhumanist Association (2002–2005) (PDF). *The transhumanist FAQ* (http://www.transhumanism.org/resources/FAQv21.pdf). . Retrieved 2006-08-27.

[27] Sandberg, Anders (undated). *Definitions of Transhumanism* (http://www.aleph.se/Trans/Intro/definitions.html). . Retrieved 2006-05-05.

[28] Ford, Alyssa (May / June 2005). "Humanity: The Remix" (http://www.utne.com/2005-05-01/humanity-the-remix.aspx). *Utne Magazine*. . Retrieved 2007-03-03.
[29] Saletan, William (2006-06-04). "Among the Transhumanists" (http://web.archive.org/web/20061231222833/http://www.slate.com/id/2142987/fr/rss/). Slate.com. Archived from the original (http://www.slate.com/id/2142987/fr/rss/) on 2006-12-31. . Retrieved 2007-03-03.
[30] Extropy Institute (2006). *Next Steps* (http://www.extropy.org/future.htm). . Retrieved 2006-05-05.
[31] Blackford, Russell (2008). *WTA changes its image* (http://metamagician3000.blogspot.com/2008/07/wta-changes-its-image.html). . Retrieved 2008-11-18.
[32] "h+ Magazine" (http://www.hplusmagazine.com/). .
[33] Newitz, Annalee (2008). *Can Futurism Escape the 1990s?* (http://io9.com/5067829/can-futurism-escape-the-1990s). . Retrieved 2008-11-18.
[34] Italy elects first transhumanist MP (http://www.kurzweilai.net/italy-elects-first-transhumanist-mp)
[35] Hook, Christopher (2004). "Transhumanism and Posthumanism" (http://gale.cengage.com/pdf/samples/sp657748.pdf). In Stephen G. Post. *Encyclopedia of Bioethics* (3rd ed.). New York: Macmillan. pp. 2517–2520. ISBN 0-02-865774-8. OCLC 52622160. . Retrieved 2007-12-10.
[36] Winner, Langdon (Fall 2002). "Are Humans Obsolete?" (http://www.virginia.edu/iasc/HHR_Archives/Technology/4.3DWinner.pdf) (PDF). *The Hedgehog Review*. . Retrieved 2007-12-10.
[37] Coenen, Christopher (2007). "Utopian Aspects of the Debate on Converging Technologies" (http://www.itas.fzk.de/deu/lit/epp/2007/coen07-pre01.pdf). In Gerhard Banse et al.. *Assessing Societal Implications of Converging Technological Development* (1st ed.). Berlin: edition sigma. pp. 141–172. ISBN 978-3-89404-941-6. OCLC 198816396. . Retrieved 2008-08-19.
[38] Bostrom, Nick. "Why I Want to be a Posthuman When I Grow Up" (http://www.nickbostrom.com/posthuman.pdf) (PDF). . Retrieved 2007-12-10.
[39] Badmington, Neil (Winter 2003). "Theorizing Posthumanism" (http://muse.jhu.edu/login?uri=/journals/cultural_critique/v053/53.1badmington.html). *Cultural Critique*. . Retrieved 2007-12-10.
[40] Hayles, N. Katherine (1999). *How We Became Posthuman: Virtual Bodies in Cybernetics, Literature, and Informatics*. University Of Chicago Press. ISBN 0-226-32146-0. OCLC 186409073.
[41] Inniss, Patrick. "Transhumanism: The Next Step?" (http://www.secularhumanism.org/library/aah/inniss_8_4.htm). . Retrieved 2007-12-10.
[42] Winner, Langdon. "Resistance is Futile: The Posthuman Condition and Its Advocates" (http://books.google.co.uk/books?id=zwolIIz9zg0C&pg=PA385&lpg=PA385&dq=Resistance+is+Futile:+The+Posthuman+Condition+and+Its+Advocates&source=bl&ots=3LBSv1O7mY&sig=-u4q1XC-5nObCwjCI7FiIHA8W78&hl=en&sa=X&ei=79u2T_2aNMjZ0QXIs6z4Bw&ved=0CFQQ6AEwAQ#v=onepage&q=Resistance is Futile: The Posthuman Condition and Its Advocates&f=false). In Harold Bailie, Timothy Casey. *Is Human Nature Obsolete?*. Massachusetts Institute of Technology: M.I.T. Press. pp. 385–411. ISBN 0262524287. .
[43] Kurzweil, Raymond (2005). *The Singularity Is Near: When Humans Transcend Biology*. Viking Adult. ISBN 0-670-03384-7. OCLC 224517172.
[44] Bostrom, Nick (2002). *Existential risks: analyzing human extinction scenarios* (http://www.nickbostrom.com/existential/risks.html). . Retrieved 2006-02-21.
[45] Bostrom, Nick & Sandberg, Anders (2007) (PDF). *The Wisdom of Nature: An Evolutionary Heuristic for Human Enhancement* (http://www.nickbostrom.com/evolution.pdf). . Retrieved 2007-09-18.
[46] Hughes, James (2002). *The politics of transhumanism* (http://www.changesurfer.com/Acad/TranshumPolitics.htm). . Retrieved 2006-02-26.
[47] World Transhumanist Association (2002–2005). *What currents are there within transhumanism?* (http://web.archive.org/web/20071016194900/http://www.transhumanism.org/index.php/WTA/faq21/81/). Archived from the original (http://www.transhumanism.org/index.php/WTA/faq21/81/) on October 16, 2007. . Retrieved 2007-11-03.
[48] The Abolitionist Society. "Abolitionism" (http://web.archive.org/web/20070201231438/http://www.abolitionist-society.com/abolitionism.htm). Archived from the original (http://www.abolitionist-society.com/abolitionism.htm) on February 1, 2007. . Retrieved 2007-01-03.
[49] Hughes, James (2002). *Democratic Transhumanism 2.0* (http://www.changesurfer.com/Acad/DemocraticTranshumanism.htm). . Retrieved 2007-01-26.
[50] "Immortality Institute" (http://www.imminst.org/). .
[51] Dvorsky, George (2008). *Postgenderism: Beyond the Gender Binary* (http://sentientdevelopments.blogspot.com/2008/03/postgenderism-beyond-gender-binary.html). . Retrieved 2008-04-13.
[52] Raël (2002). *Oui au clonage humain: La vie éternelle grâce à la science*. Quebecor. ISBN 1-903571-05-7. OCLC 226022543.
[53] Hughes, James (2004). *Technologies of Self-perfection: What would the Buddha do with nanotechnology and psychopharmaceuticals?* (http://web.archive.org/web/20070510094442/http://archives.betterhumans.com/Columns/Column/tabid/79/Column/222/Default.aspx). Archived from the original (http://archives.betterhumans.com/Columns/Column/tabid/79/Column/222/Default.aspx) on May 10, 2007. . Retrieved 2007-02-21.
[54] Sandberg, Anders (2000). *Uploading* (http://www.aleph.se/Trans/Global/Uploading/). . Retrieved 2006-03-04.
[55] Tipler, Frank J. (1994). *The Physics of Immortality*. Doubleday. ISBN 0-19-282147-4. OCLC 16830384.

[56] Eric Steinhart (December 2008). "Teilhard de Chardin and Transhumanism" (http://jetpress.org/v20/steinhart.htm?pagewanted=all). *Journal of Evolution and Technology* **20** (1): 1–22. .

[57] Michael S. Burdett (2011). *Transhumanism and Transcendence*. Georgetown University Press. p. 20. ISBN 978-1-58901-780-1. "...others have made important contributions as well. For example, Freeman Dyson and Frank Tipler in the twentieth century..."

[58] Pauls, David (2005). *Transhumanism: 2000 Years in the Making* (http://web.archive.org/web/20061010102349/http://www.thecbc.org/redesigned/research_display.php?id=189). Archived from the original (http://www.thecbc.org/redesigned/research_display.php?id=189) on October 10, 2006. . Retrieved 2006-12-05.

[59] Giesen, Klaus-Gerd (2004). *Transhumanisme et génétique humaine* (http://www.omics-ethics.org/observatoire/cadrages/cadr2004/c_no16_04/c_no16_04_01.html). . Retrieved 2006-04-26.

[60] Davis, Erik (1999). *TechGnosis: Myth, Magic, and Mysticism in the Age of Information*. Three Rivers Press. ISBN 0-609-80474-X. OCLC 42925424.

[61] Campbell, Heidi; Walker, Mark Alan (2005). *Religion and transhumanism: introducing a conversation* (http://www.jetpress.org/volume14/specialissueintro.html). . Retrieved 2006-03-21.

[62] "TransVision 2004: Faith, Transhumanism and Hope Symposium" (http://www.transhumanism.org/tv/2004/program.shtml#Faith). .

[63] Bainbridge, William Sims (2005). *The Transhuman Heresy* (http://jetpress.org/volume14/bainbridge.html). . Retrieved 2008-01-02.

[64] "AAR: Transhumanism and Religion Consultations" (http://www.aarweb.org/meetings/Annual_Meeting/Program_Units/PUinformation.asp?PUNum=AARPU187). .

[65] Walker, Mark Alan (March 2002). "Prolegomena to any future philosophy" (http://www.jetpress.org/volume10/prolegomena.html). *Journal of Evolution and Technology* **10** (1). ISSN 1541-0099. . Retrieved 2006-03-02.

[66] Kurzweil, Raymond (1993). *The 10% Solution for a Healthy Life*. Three Rivers Press.

[67] Kurzweil, Raymond (2004). *Fantastic Voyage: Live Long Enough to Live Forever*. Viking Adult. ISBN 1-57954-954-3. OCLC 56011093.

[68] ""Converging Technologies"" (http://www.wtec.org/ConvergingTechnologies/Report/welcome.htm). Wtec.org. . Retrieved 2012-05-18.

[69] Naam, Ramez (2005). *More Than Human: Embracing the Promise of Biological Enhancement* (http://www.morethanhuman.org/). Broadway Books. ISBN 0-7679-1843-6. OCLC 55878008. .

[70] Sandberg, Anders (2001). *Morphological freedom -- why we not just want it, but* need *it* (http://www.nada.kth.se/~asa/Texts/MorphologicalFreedom.htm). . Retrieved 2006-02-21.

[71] The Royal Society & The Royal Academy of Engineering (2004) (PDF). *Nanoscience and nanotechnologies (Ch. 6)* (http://www.nanotec.org.uk/report/chapter6.pdf). . Retrieved 2006-12-05.

[72] Moreno, Jonathan D. (2006). *Mind Wars: Brain Research and National Defense*. Dana Press. ISBN 1-932594-16-7.

[73] Goldblatt, Michael (2002). "DARPA's programs in enhancing human performance". In Roco, Mihail C.; Bainbridge, William Sims. *Managing Nano-Bio-Info-Cogno Innovations: Converging Technologies in Society* (1 ed.). Arlington, VA: Springer. pp. 339–340. ISBN 1-4020-4106-3.; cited in McIntosh, Daniel (December 2008). "Human, Transhuman, Posthuman: Implications of Evolution-by-design for Human Security". *Journal of Human Security* **4** (3): 4–20. doi:10.3316/JHS0403004. ISSN 1835-3800.

[74] "The transhuman factor" (http://www.montrealmirror.com/wp/2011/08/18/cover-the-transhuman-factor/). Montreal Mirror. 2011-10-14. . Retrieved 2012-05-18.

[75] Wilson, Cintra (2007-10-21). "Droid Rage" (http://www.nytimes.com/2007/10/21/style/tmagazine/21droid.html?_r=1&ref=tmagazine&oref=slogin). *The New York Times*: p. 46. . Retrieved 2008-01-11.

[76] O'Bryan, C. Jill (2005). *Carnal Art:Orlan's Refacing*. University of Minnesota Press. ISBN 0-8166-4322-9. OCLC 56755659.

[77] Smith, Simon (2003). *Looking at the Man in the Mirror* (http://web.archive.org/web/20071219104730/http://archives.betterhumans.com/Columns/Column/tabid/79/Column/332/Default.aspx). Archived from the original (http://archives.betterhumans.com/Columns/Column/tabid/79/Column/332/Default.aspx) on 2007-12-19. . Retrieved 2009-06-29.

[78] Alexander, Brian (2004). *Rapture: A Raucous Tour Of Cloning, Transhumanism, And And The New Era Of Immortality* (1st ed.). Basic Books. ISBN 0-465-00105-X.

[79] Garreau, Joel (2006). *Radical Evolution: The Promise and Peril of Enhancing Our Minds, Our Bodies -- and What It Means to Be Human*. Broadway. ISBN 0-7679-1503-8. OCLC 68624303.

[80] Clark, Amanda C. R. (March 12, 2010). "Transhumanism and Posthumanism: Lifting Man Up or Pulling Him Down?" (http://www.ignatiusinsight.com/features2010/aclark_tranhumanism_mar2010.asp). Ignatius Insight. . Retrieved 2012-05-18.

[81] Dublin, Max (1992). *Futurehype: The Tyranny of Prophecy*. Plume. ISBN 0-452-26800-1. OCLC 236056666.

[82] Stock, Gregory (2002). *Redesigning Humans: Choosing our Genes, Changing our Future*. Mariner Books. ISBN 0-618-34083-1. OCLC 51756081.

[83] International Theological Commission (2002). *Communion and stewardship: human persons created in the image of God* (http://www.vatican.va/roman_curia/congregations/cfaith/cti_documents/rc_con_cfaith_doc_20040723_communion-stewardship_en.html). . Retrieved 2006-04-01.

[84] Mitchell, Ben C. & Kilner, John F. (2003). *Remaking Humans: The New Utopians Versus a Truly Human Future* (http://www.cbhd.org/resources/biotech/mitchell_kilner_2003-08-29.htm). . Retrieved 2006-12-05.

[85] Barratt, Helen (2006). *Transhumanism* (http://www.cmf.org.uk/literature/content.asp?context=article&id=1717.#). . Retrieved 2006-12-05.

[86] Rifkin, Jeremy (1983). *Algeny: A New Word--A New World*. Viking Adult. ISBN 0-670-10885-5.

[87] Newman, Stuart A. (2003). "Averting the clone age: prospects and perils of human developmental manipulation" (http://genetics.live.radicaldesigns.org/downloads/200303_jchlp_newman.pdf) (PDF). *J. Contemp. Health Law & Policy* **19**: 431. . Retrieved 2008-09-17.

[88] Smolensky, Kirsten Rabe (2006). *Parental liability for germline genetic enhancement: to be or not to be? (Public address, Stanford University)* (http://ieet.org/index.php/IEET/HETHR_bios/smolensky/). . Retrieved 2006-06-18.

[89] Cole-Turner, Ronald (1993). *The New Genesis: Theology and the Genetic Revolution*. Westminster John Knox Press. ISBN 0-664-25406-3. OCLC 26402489.

[90] Peters, Ted (1997). *Playing God?: Genetic Determinism and Human Freedom*. Routledge. ISBN 0-415-91522-8. OCLC 35192269.

[91] Midgley, Mary (1992). *Science as Salvation*. Routledge. ISBN 0-415-06271-3. OCLC 181929611.

[92] Bordo, Susan (1993). *Unbearable Weight: Feminism, Western Culture and the Body*. University of California Press. ISBN 0-520-08883-2. OCLC 27069938.

[93] Alexander, Brian (2000). *Don't die, stay pretty: introducing the ultrahuman makeover* (http://www.wired.com/wired/archive/8.01/forever.html). . Retrieved 2007-01-08.

[94] McKibben, Bill (2003). *Enough: Staying Human in an Engineered Age*. Times Books. ISBN 0-8050-7096-6. OCLC 237794777.

[95] Bailey, Ronald (2003). *Enough Already* (http://web.archive.org/web/20060320205635/http://www.reason.com/0310/cr.rb.enough.shtml). Archived from the original (http://www.reason.com/0310/cr.rb.enough.shtml) on 2006-03-20. . Retrieved 2006-05-31.

[96] Silver, Lee M. (1998). *Remaking Eden: Cloning and Beyond in a Brave New World*. Harper Perennial. ISBN 0-380-79243-5. OCLC 40094564.

[97] Kass, Leon (May 21, 2001). "Preventing a Brave New World: why we must ban human cloning now". The New Republic.

[98] Habermas, Jürgen (2004). *The Future of Human Nature*. Polity Press. ISBN 0-7456-2987-3. OCLC 49395577.

[99] Platt, Charles (1995). *Superhumanism* (http://www.wired.com/wired/archive/3.10/moravec.html). . Retrieved 2006-12-05.

[100] Blackford, Russell (2003). *Who's afraid of the Brave New World?* (http://web.archive.org/web/20060823035344/http://www.users.bigpond.com/russellblackford/brave_new_world.htm). Archived from the original (http://www.users.bigpond.com/russellblackford/brave_new_world.htm) on August 23, 2006. . Retrieved 2006-02-08.

[101] Otchet, Amy (1998). *Jeremy Rifkin: fears of a brave new world* (http://web.archive.org/web/20050910013827/http://www.unesco.org/courier/1998_09/uk/dires/txt1.htm). Archived from the original (http://www.unesco.org/courier/1998_09/uk/dires/txt1.htm) on 2005-09-10. . Retrieved 2006-02-20.

[102] Lee, Keekok (1999). *The Natural and the Artefactual*. Lexington Books. ISBN 0-7391-0061-0. OCLC 231842178.

[103] Darnovsky, Marcy (2001). *Health and human rights leaders call for an international ban on species-altering procedures* (http://www.genetics-and-society.org/newsletter/archive/20.html). . Retrieved 2006-02-21.

[104] Bailey, Ronald (2001). *Right-Wing Biological Dread: The Subhumans are coming! The Subhumans are coming!* (http://www.reason.com/news/show/34926.html). . Retrieved January 18, 2007.

[105] Glenn, Linda MacDonald (2003). *Biotechnology at the margins of personhood: an evolving legal paradigm* (http://ieet.org/index.php/IEET/articles/glennjet2003/). . Retrieved 2006-03-03.

[106] Black, Edwin (2003). *War Against the Weak: Eugenics and America's Campaign to Create a Master Race*. Four Walls Eight Windows. ISBN 1-56858-258-7.

[107] [Bashford, A.]] and Levine, P. (2010). *The Oxford Handbook of The History of Eugenics*. Oxford University Press. p. 545. ISBN 9780195373141.

[108] World Transhumanist Association (2002–2005). *Do transhumanists advocate eugenics?* (http://web.archive.org/web/20060909005028/http://www.transhumanism.org/index.php/WTA/faq21/66/). Archived from the original (http://www.transhumanism.org/index.php/WTA/faq21/66/) on September 9, 2006. . Retrieved 2006-04-03.

[109] Buchanan, Allen; Brock, Dan W.; Daniels, Norman; Wikler, Daniel (2000). *From Chance to Choice: Genetics and Justice*. Cambridge University Press. ISBN 0-521-66977-4. OCLC 41211380.

[110] Humphrey, Stephen (2004). *No death, please, I'm bionic* (http://www.nowtoronto.com/news/story.cfm?content=143132&archive=23,50,2004). . Retrieved 2006-02-21.

[111] Kaczynski, Theodore (1995). *Industrial Society and Its Future*. Retrieved on 2006-02-21.

[112] Joy, Bill (2000). *Why the future doesn't need us* (http://www.wired.com/wired/archive/8.04/joy_pr.html). . Retrieved 2005-11-14.

[113] Walker, Ian (2001). *Cyborg Dreams: Beyond Human* (http://www.abc.net.au/cgi-bin/common/printfriendly.pl?http://www.abc.net.au/rn/talks/bbing/stories/s409607.htm). . Retrieved 2012-01-17.

[114] Hughes, James (2005). "Tech for People, not for Corporate Control: Interview with Kalle Lasn, founder of AdBusters" (http://www.radio4all.net/proginfo.php?id=11260). . Retrieved 2006-06-12.

[115] Rees, Martin (2003). *Our Final Hour: A Scientist's Warning: How Terror, Error, and Environmental Disaster Threaten Humankind's Future In This Century—On Earth and Beyond*. Basic Books. ISBN 0-465-06862-6. OCLC 51315429.

[116] Arnall, Alexander Huw (2003) (PDF). *Future technologies, today's choices: nanotechnology, artificial intelligence and robotics* (http://www.greenpeace.org.uk/MultimediaFiles/Live/FullReport/5886.pdf). Greenpeace U.K. . Retrieved 2006-04-29.

[117] Layman, Dale (2002). *Robowatch 2002: Mankind At The Brink* (http://www.robowatch.org/main2.html). London Diplomatic Academy. . Retrieved 2007-01-23.

[118] Dvorsky, George (2003). *Technophiles and Greens of the World, Unite!* (http://web.archive.org/web/20070510094545/http://archives.betterhumans.com/Columns/Column/tabid/79/Column/305/Default.aspx). Archived from the original (http://archives.betterhumans.com/Columns/Column/tabid/79/Column/305/Default.aspx) on May 10, 2007. . Retrieved 2007-03-19.

[119] Verdoux, Philippe (2009). *Transhumanism, Progress and the Future* (http://jetpress.org/v20/verdoux.htm). . Retrieved 2010-03-19.

</ref> -->

}}

Further reading

- Cole-Turner, R. (ed.). 2011. *Transhumanism and transcendence: Christian hope in an age of technological advancement*. Georgetown University Press. ISBN 978-1-58901-780-1.

Outline of transhumanism

The following outline is provided as an overview of and topical guide to transhumanism:

Transhumanism – international intellectual and cultural movement that affirms the possibility and desirability of fundamentally transforming the human condition by developing and making widely available technologies to eliminate aging and to greatly enhance human intellectual, physical, and psychological capacities.[1] Transhumanist thinkers study the potential benefits and dangers of emerging technologies that could overcome fundamental human limitations, as well as study the ethical matters involved in developing and using such technologies.[1] They predict that human beings may eventually be able to transform themselves into beings with such greatly expanded abilities as to merit the label "posthuman".[1] Transhumanism is often abbreviated as *H+* or *h+* ("humanism plus").

Transhumanist currents

- Abolitionism – ethical ideology based upon a perceived obligation to use technology to eliminate involuntary suffering in all sentient life.[2]
- Democratic transhumanism – political ideology synthesizing liberal democracy, social democracy, radical democracy and transhumanism.[3]
- Extropianism – early school of transhumanist thought characterized by a set of principles advocating a proactive approach to human evolution.[4]
- Immortalism – moral ideology based upon the belief that technological immortality is possible and desirable, and advocating research and development to ensure its realization.[5]
- Libertarian transhumanism – political ideology synthesizing libertarianism and transhumanism.[6]
- Postgenderism – social philosophy which seeks the voluntary elimination of gender in the human species through the application of advanced biotechnology and assisted reproductive technologies.[7]
- Singularitarianism – moral ideology based upon the belief that a technological singularity is possible, and advocating deliberate action to affect it and ensure its safety.[8]
- Technogaianism – ecological ideology based upon the belief that emerging technologies can help restore Earth's environment, and that developing safe, clean, alternative technology should therefore be an important goal of environmentalists.[3]

Transhumanist technologies

Transhumanists believe that humans can and should use technologies to become more than human. Examples of the types of technologies and potential technologies that have become the focus of transhumanism include:

- Anti-aging – another term for "life extension".
- Artificial intelligence – intelligence of machines and the branch of computer science that aims to create it. AI textbooks define the field as "the study and design of intelligent agents",[9] where an intelligent agent is a system that perceives its environment and takes actions that maximize its chances of success.[2] John McCarthy, who coined the term in 1956,[3] defines it as "the science and engineering of making intelligent machines."[10]
  - Friendly artificial intelligence – artificial intelligence (AI) that has a positive rather than negative effect on humanity. Friendly AI also refers to the field of knowledge required to build such an AI. AIs may be harmful to humans if steps are not taken to specifically design them to be benevolent. Doing so effectively is the primary goal of Friendly AI.
- Augmented reality – live, direct or indirect, view of a physical, real-world environment whose elements are augmented by computer-generated sensory input such as sound, video, graphics or GPS data. It is related to a more general concept called mediated reality, in which a view of reality is modified (possibly even diminished rather than augmented) by a computer. As a result, the technology functions by enhancing one's current perception of reality. By contrast, virtual reality replaces the real world with a simulated one.
- Biomedical engineering – application of engineering principles and design concepts to biology and medicine, to improve healthcare diagnosis, monitoring and therapy.[11] Applications include the development of biocompatible prostheses, clinical equipment, micro-implants, imaging equipment such as MRIs and EEGs, regenerative tissue growth, pharmaceutical drugs and therapeutic biologicals.
  - Neural engineering – discipline that uses engineering techniques to understand, repair, replace, enhance, or otherwise exploit the properties of neural systems. Neural engineers are uniquely qualified to solve design problems at the interface of living neural tissue and non-living constructs. Also known as "neuroengineering".
    - Neurohacking – colloquial term encompassing all methods of manipulating or interfering with the structure and/or function of neurons for improvement or repair.
- Biotechnology – field of applied biology that uses living organisms and bioprocesses in engineering, technology, medicine, and manufacturing, among other fields. It encompasses a wide range of procedures for modifying living organisms for human purposes. Early examples of biotechnology include domestication of animals, cultivation of plants, and breeding through artificial selection and hybridization.
  - Bionics – in medicine, this refers to the replacement or enhancement of organs or other body parts by mechanical versions. Bionic implants differ from mere prostheses by mimicking the original function very closely, or even surpassing it.
    - Cyborg – being with both biological and artificial (e.g. electronic, mechanical or robotic) parts.
  - Brain-computer interface – direct communication pathway between the brain and an external device. BCIs are under development to assist, augment, or repair human cognitive and sensory-motor functions. Sometimes called a direct neural interface or a brain–machine interface (BMI).
  - Cloning – in biotechnology, this refers to processes used to create copies of DNA fragments (molecular cloning), cells (cell cloning), or organisms.
    - Human cloning – creation of a genetically identical copy of a human. It does not usually refer to monozygotic multiple births nor the reproduction of human cells or tissue. The term is generally used to refer to artificial human cloning; human clones in the form of identical twins are commonplace, with their cloning occurring during the natural process of reproduction.
    - Therapeutic cloning – application of somatic-cell nuclear transfer (a laboratory technique for creating a clonal embryo using an ovum with a donor nucleus) in regenerative medicine.

- Cognitive science – interdisciplinary scientific study of mind and its processes. It examines what cognition is, what it does and how it works. It includes research on how information is processed (in faculties such as perception, language, memory, reasoning, and emotion), represented, and transformed in behaviour, (human or other animal) nervous system or machine (e.g., computer). It includes research on artificial intelligence.
- Computer-mediated reality – ability to add to, subtract information from, or otherwise manipulate one's perception of reality through the use of a wearable computer or hand-held device[12] such as a smart phone.
- Converging technologies –
- Cryonics – low-temperature preservation of humans and animals who can no longer be sustained by contemporary medicine, with the hope that healing and resuscitation may be possible in the future. Cryopreservation of people or large animals is not reversible with current technology.
- Cyberware – hardware or machine parts implanted in the human body and acting as an interface between the central nervous system and the computers or machinery connected to it. Research in this area is a protoscience.
- Designer baby – baby whose genetic makeup has been artificially selected by genetic engineering combined with in vitro fertilisation to ensure the presence or absence of particular genes or characteristics.[13]
- Emerging technologies – contemporary advances and innovation in various fields of technology, prior to or early in their diffusion. They are typically in the form of progressive developments intended to achieve a competitive advantage.[14]
  - List of emerging technologies
- Human enhancement technologies (HET) – techniques used to treat illness or disability, or to enhance human characteristics and capacities.[15]
- Human genetic engineering – alteration of an individual's genotype with the aim of choosing the phenotype of a newborn or changing the existing phenotype of a child or adult.[16]
- Human-machine interface – the part of a machine that handles its human-machine interaction.
- Information technology – acquisition, processing, storage and dissemination of vocal, pictorial, textual and numerical information by a microelectronics-based combination of computing and telecommunications.[17]
- Head-mounted display (HMD) – display device, worn on the head or as part of a helmet, that has a small display optic in front of one (monocular HMD) or each eye (binocular HMD).
- Life extension – study of slowing down or reversing the processes of aging to extend both the maximum and average lifespan. Some researchers in this area, and persons who wish to achieve longer lives for themselves (called "life extensionists" or "longevists"), expect that future breakthroughs in tissue rejuvenation with stem cells, molecular repair, and organ replacement (such as with artificial organs or xenotransplantations) will eventually enable humans to live indefinitely (agerasia[18]) through complete rejuvenation to a healthy youthful condition. Also known as anti-aging medicine, experimental gerontology, and biomedical gerontology.
- Mind uploading – hypothetical process of transferring or copying a conscious mind from a brain to a non-biological substrate by scanning and mapping a biological brain in detail and copying its state into a computer system or another computational device. The computer would have to run a simulation model so faithful to the original that it would behave in essentially the same way as the original brain, or for all practical purposes, indistinguishably.[19]
- Nanotechnology – study of physical phenomena on the nanoscale, dealing with things measured in nanometres, billionths of a meter. The development of microscopic or molecular machines.
  - Molecular nanotechnology – technology based on the ability to build structures to complex, atomic specifications by means of mechanosynthesis.[20]
    - Molecular assemblers – as defined by K. Eric Drexler, is a "proposed device able to guide chemical reactions by positioning reactive molecules with atomic precision". Some biological molecules such as ribosomes fit this definition, because they receive instructions from messenger RNA and then assemble specific sequences of amino acids to construct protein molecules. However, the term "molecular assembler" usually refers to theoretical human-made devices.

- Nootropics – drugs, supplements, nutraceuticals, and functional foods that improve mental functions such as cognition, memory, intelligence, motivation, attention, and concentration.[21][22] Also referred to as "smart drugs", "brain steroids", "memory enhancers", "cognitive enhancers", "brain boosters", and "intelligence enhancers".
- Organ transplants – moving of an organ from one body to another or from a donor site on the patient's own body, for the purpose of replacing the recipient's damaged or absent organ. The emerging field of regenerative medicine is allowing scientists and engineers to create organs to be re-grown from the patient's own cells (stem cells, or cells extracted from the failing organs).
  - Autograft – organs and/or tissues that are transplanted within the same person's body.
  - Allograft – transplants that are performed between two subjects of the same species.
  - Xenograft – living cells, tissues or organs transplanted from one species to another.
- Personal communicators – Around 1990 the next generation digital mobile phones were called digital personal communicators. Another definition, coined in 1991, is for a category of handheld devices that provide personal information manager functions and packet switched wireless data communications capabilities over wireless wide area networks such as cellular networks. These devices are now commonly referred to as smartphones or wireless PDA's.
- Personal development – includes activities that improve awareness and identity, develop talents and potential, build human capital and facilitates employability, enhance quality of life and contribute to the realization of dreams and aspirations. The concept is not limited to self-help, but includes formal and informal activities for developing others, in roles such as teacher, guide, counselor, manager, coach, or mentor. Finally, as personal development takes place in the context of institutions, it refers to the methods, programs, tools, techniques, and assessment systems that support human development at the individual level in organizations.[23]
- Powered exoskeleton – powered mobile machine consisting primarily of an exoskeleton-like framework worn by a person and a power supply that supplies at least part of the activation-energy for limb movement. Also known as "powered armor", or "exoframe".
- Prosthetics – artificial device extensions that replace missing body parts.
- Rejuvenation – reversal of aging, which entails the repair of the damage associated with aging, or replacement of damaged tissue with new tissue. Rejuvenation can be a means of life extension, but most life extension strategies do not involve rejuvenation.
- Robotics – design, construction, operation, structural disposition, manufacture and application of robots. It draws heavily upon electronics, engineering, mechanics mechatronics, and software engineering.
  - Self-replicating machine – artificial construct that is theoretically capable of autonomously manufacturing a copy of itself using raw materials taken from its environment, thus exhibiting self-replication in a way analogous to that found in nature.
- Reprogenetics – merging of reproductive and genetic technologies expected to happen in the near future as techniques like germinal choice technology become more available and more powerful.
- Simulated reality –
- Space colonization – concept of permanent human habitation outside of Earth. Although hypothetical at the present time, there are many proposals and speculations about the first space colony. It is a long-term goal of some national space programs. Also called "space settlement", "space humanization", and "space habitation".
- Suspended animation – slowing of life processes by external means without termination. Breathing, heartbeat, and other involuntary functions may still occur, but they can only be detected by artificial means. Extreme cold can be used to precipitate the slowing of an individual's functions. For example, Laina Beasley was kept in suspended animation as a two-celled embryo for 13 years.[24][25]
- Virtual retinal display – display technology that draws a raster display (like a television) directly onto the retina of the eye. Users see what appears to be a conventional display floating in space in front of them.

History of transhumanism

- Renaissance humanism – cultural and educational reform during the fourteenth and the beginning of the fifteenth centuries, as a response to the challenge of Mediæval scholastic education, emphasizing practical, pre-professional and -scientific studies. Rather than train professionals in jargon and strict practice, humanists sought to create a citizenry (sometimes including women) able to speak and write with eloquence and clarity.
- Age of Enlightenment – elite cultural movement of intellectuals in 18th century Europe that sought to mobilize the power of reason in order to reform society and advance knowledge. It promoted intellectual interchange and opposed intolerance and abuses in church and state.

Transhumanist concepts

- *Converging Technologies for Improving Human Performance*
- Extropianism – evolving framework of values and standards for continuously improving the human condition. Extropians believe that advances in science and technology will some day let people live indefinitely. An extropian may wish to contribute to this goal, e.g. by doing research and development or volunteering to test new technology.
- Futures studies – study of postulating possible, probable, and preferable futures and the worldviews and myths that underlie them. Also called "futurology".
- GNR – denotes the technologies of genetics, nanotechnology, and robotics.[26]
- Human condition – the irreducible part of humanity that is inherent and not connected to gender, race, class, etc.; the experiences of being human in a social, cultural, and personal context. Transhumanism aims to radically improve the human condition.
- Human enhancement[27] –
- Survival –
  - Existential risks – dangers that have the potential to destroy, or drastically restrict, human civilization.[28] They are distinguished from other forms of risk both by their scope, affecting all of humanity, and severity; destroying or irreversibly crippling the target.
  - Human extinction –
    - Human extinction scenarios –
  - Longevity –
    - Immortality –
    - Indefinite lifespan –
- Megatrajectory – theoretical concept in evolutionary biology that describes paradigmatic developmental stages (major evolutionary milestones) and potential directionality in the evolution of life. A theorized megatrajectory that hasn't occurred yet is postbiological evolution triggered by the emergence of strong AI and several other similarly complex technologies.
- Morphological freedom – proposed civil right of a person to either maintain or modify his or her own body, on his or her own terms, through informed, consensual recourse to, or refusal of, available therapeutic or enabling medical technology.[29]
- Noosphere – "sphere of human thought".[30] In the original theory of Vernadsky, the noosphere (sentience) is the third in a succession of phases of development of the Earth, after the geosphere (inanimate matter) and the biosphere (biological life).
- Omega Point – term coined by the French Jesuit Pierre Teilhard de Chardin (1881–1955) to describe a maximum level of complexity and consciousness towards which he believed the universe was evolving.
- Participant evolution – process of deliberately redesigning the human body and brain using technological means, rather than through the natural processes of mutation and natural selection, with the goal of removing "biological limitations."

- Procreative beneficence –
- Procreative liberty –
- Posthumanism –
  - Posthuman[31] – in transhumanism, it is a hypothetical future being "whose basic capacities so radically exceed those of present humans as to be no longer unambiguously human by our current standards."[31]
    - Parahuman – human-animal hybrid or chimera. Scientists have done extensive research into the mixing of genes or cells from different species, e.g. adding human (and other animal) genes to bacteria and farm animals to mass-produce insulin and spider silk proteins, and introducing human cells into mouse embryos.
    - Posthuman God – idea that posthumans, being no longer confined to the parameters of human nature, might grow physically and mentally so powerful as to appear god-like by human standards.[31]
- Post scarcity – hypothetical form of economy or society, in which things such as goods, services and information are free, or practically free. This would be due to an abundance of fundamental resources (matter, energy and intelligence), in conjunction with sophisticated automated systems capable of converting raw materials into finished goods, allowing manufacturing to be as easy as duplicating software.
- Singularitarianism – technocentric ideology and social movement defined by the belief that a technological singularity—the creation of a superintelligence—will likely happen in the medium future, and that deliberate action ought to be taken to ensure that the Singularity benefits humans.
- Technogaianism – bright green environmentalist stance of active support for the research, development and use of emerging and future technologies to help restore Earth's environment. Technogaians argue that developing safe, clean, alternative technology should be an important goal of environmentalists.[32]
- Technological convergence – tendency for different technological systems to evolve towards performing similar tasks. Convergence can refer to previously separate technologies such as voice (and telephony features), data (and productivity applications), and video that now share resources and interact with each other synergistically.
- Technological singularity – hypothetical future emergence of greater-than-human intelligence through technological means. Since the capabilities of such an intelligence would be difficult for an unaided human mind to comprehend, the occurrence of a technological singularity is seen as an intellectual event horizon, beyond which the future becomes difficult to understand or predict. Nevertheless, proponents of the singularity typically anticipate such an event to precede an "intelligence explosion", wherein superintelligences design successive generations of increasingly powerful minds.
- Technophilia – strong enthusiasm for technology, especially new technologies such as personal computers, the Internet, mobile phones and home cinema. The term is used in sociology when examining the interaction of individuals with their society, especially contrasted with technophobia.
- Techno-utopianism – any ideology based on the belief that advances in science and technology will eventually bring about a utopia, or at least help to fulfill one or another utopian ideal. A techno-utopia is therefore a hypothetical ideal society, in which laws, government, and social conditions are solely operating for the benefit and well-being of all its citizens, set in the near- or far-future, when advanced science and technology will allow these ideal living standards to exist; for example, post scarcity, transformations in human nature, the abolition of suffering and even the end of death.

Transhumanist organizations

- Applied Foresight Network – global web of university-based centres connected by a network of forums for professors, students, teachers, and concerned citizens. The AFN supports informed discussion and social action on issues of critical importance to the future of humanity.
- Alcor Life Extension Foundation – nonprofit company based in Scottsdale, Arizona, USA that researches, advocates for and performs cryonics, the preservation of humans in liquid nitrogen after legal death, in the hope of restoring them to full health when new technology is developed in the future.
- Foresight Institute – nonprofit organization based in Palo Alto, California that promotes transformative technologies. They sponsor conferences on molecular nanotechnology, publish reports, produce a newsletter, and offer several running prizes, including the annual Feynman Prizes given in experimental and theory categories, and the $250,000 Feynman Grand Prize for demonstrating two molecular machines capable of nanoscale positional accuracy and computation.[33]
- Humanity+ – international non-governmental organization which advocates the ethical use of emerging technologies to enhance human capacities. It was formerly named the "World Transhumanist Association".
- Immortality Institute – nonprofit organisation whose mission is "to conquer the blight of involuntary death". It maintains an online forum for information exchange, has published a book,[34] produced a film,[35] has organized three international conferences,[36] and also sponsors small-scale scientific initiatives.
- Singularity Institute for Artificial Intelligence – non-profit organization founded in 2000 to develop safe artificial intelligence software, and to raise awareness of both the dangers and potential benefits it believes AI presents. In their view, the potential benefits and risks of a technological singularity necessitate the search for solutions to problems involving AI goal systems to ensure powerful AIs are not dangerous when they are created.[37][38]

Leaders and scholars in transhumanism

Some people who have made a major impact on the advancement of transhumanism:

- Nick Bostrom –
- George Dvorsky –
- Robert Ettinger –
- K. Eric Drexler –
- Nikolai Fyodorovich Fyodorov
- FM-2030 (October 15, 1930, – July 8, 2000) – author, teacher, transhumanist philosopher, futurist, and consultant.[39] His given name was Fereidoun M. Esfandiary. He became notable as a transhumanist with the book *Are You a Transhuman?: Monitoring and Stimulating Your Personal Rate of Growth in a Rapidly Changing World*, published in 1989.
- Aubrey de Grey – English author and theoretician in the field of gerontology, and the Chief Science Officer of the SENS Foundation. He is perhaps best known for his view that human beings could, in theory, live to lifespans far in excess of that which any authenticated cases have lived to today.
- James Hughes –
- Julian Huxley –
- Raymond Kurzweil –
- Hans Moravec – adjunct faculty member at the Robotics Institute of Carnegie Mellon University. He is known for his work on robotics, artificial intelligence, and writings on the impact of technology. Moravec also is a futurist with many of his publications and predictions focusing on transhumanism. Moravec developed techniques in computer vision for determining the region of interest (ROI) in a scene.
- Max More –
- David Pearce – Utilitarian thinker and author of *The Hedonistic Imperative*, in which he explores the possibility of how technologies such as genetic engineering, nanotechnology, pharmacology, and neurosurgery could

potentially converge to eliminate all forms of unpleasant experience in human life and produce a posthuman civilization.[40]

- Giulio Prisco –
- Anders Sandberg – researcher, science debater, futurist, transhumanist, and author born in Solna, Sweden, whose recent contributions include work on cognitive enhancement[41] (methods, impacts, and policy analysis); a technical roadmap on whole brain emulation;[42] on neuroethics; and on global catastrophic risks, particularly on the question of how to take into account the subjective uncertainty in risk estimates of low-likelihood, high-consequence risk.[43]
- Frank J. Tipler –
- Natasha Vita-More –

References

[1] Bostrom, Nick (2005). "A history of transhumanist thought" (http://www.nickbostrom.com/papers/history.pdf) (PDF). *Journal of Evolution and Technology*. . Retrieved 2006-02-21.

[2] The Abolitionist Society. "Abolitionism" (http://web.archive.org/web/20061104055800/http://www.abolitionist-society.com/abolitionism.htm). Archived from the original (http://www.abolitionist-society.com/abolitionism.htm) on 2006-11-04. . Retrieved 2007-01-03.

[3] Hughes, James (2002). *Democratic Transhumanism 2.0* (http://www.changesurfer.com/Acad/DemocraticTranshumanism.htm). . Retrieved 2007-01-26.

[4] More, Max (1990–2003). *Principles of extropy* (http://extropy.org/principles.htm). . Retrieved 2006-02-16.

[5] "Immortality Institute" (http://www.imminst.org/). .

[6] Hughes, James (2002). *The politics of transhumanism* (http://www.changesurfer.com/Acad/TranshumPolitics.htm). . Retrieved 2006-02-26.

[7] Dvorksy, George (2008). *Postgenderism: Beyond the Gender Binary* (http://sentientdevelopments.blogspot.com/2008/03/postgenderism-beyond-gender-binary.html). . Retrieved 2008-04-13.

[8] Kurzweil, Raymond (2005). *The Singularity Is Near: When Humans Transcend Biology*. Viking Adult. ISBN 0-670-03384-7. OCLC 224517172.

[9] Definition of AI as the study of intelligent agents:

- Poole, Mackworth & Goebel 1998, p. 1 (http://people.cs.ubc.ca/~poole/ci/ch1.pdf), which provides the version that is used in this article. Note that they use the term "computational intelligence" as a synonym for artificial intelligence.
- Russell & Norvig (2003) (who prefer the term "rational agent") and write "The whole-agent view is now widely accepted in the field" (Russell & Norvig 2003, p. 55).
- Nilsson 1998

[10] McCarthy's definition of AI:

- McCarthy 2007

[11] Biomedical engineer (http://www.prospects.ac.uk/p/types_of_job/biomedical_engineer_job_description.jsp) prospects

[12] "Wearable,Tetherless, Computer-Mediated Reality" (http://wearcam.org/mr.html), Technical Report #260, M.I.T. Medial Lab Perceptual Computing Section, Cambridge, Massachusetts, 1994

[13] Designer Babies: Ethical Considerations - Nicholas Agar - An ActionBioscience.org original article (http://www.actionbioscience.org/biotech/agar.html)

[14] International Congress Innovation and Technology XXI: Strategies and Policies Towards the XXI Century, & Soares, O. D. D. (1997). Innovation and technology: Strategies and policies. Dordrecht: Kluwer Academic.

[15] Enhancement Technologies Group (1998). *Writings by group participants* (http://www.ucl.ac.uk/~ucbtdag/bioethics/writings/index.html). . Retrieved 2007-02-02.

[16] Singer, Peter; Kuhese, Helga. *Bioethics: An Anthology*.

[17] Longley, Dennis; Shain, Michael (1985), *Dictionary of Information Technology* (2 ed.), Macmillan Press, p. 164, ISBN 0-333-37260-3

[18] "agerasia" (http://oed.com/search?searchType=dictionary&q=agerasia). *Oxford English Dictionary* (3rd ed.). Oxford University Press. 2001. .

[19] Anders, Sandberg; Nick, Boström (2008). *Whole Brain Emulation: A Roadmap* (http://www.fhi.ox.ac.uk/Reports/2008-3.pdf). Technical Report #2008-3. Future of Humanity Institute, Oxford University. . Retrieved 5 April 2009. "*The basic idea is to take a particular brain, scan its structure in detail, and construct a software model of it that is so faithful to the original that, when run on appropriate hardware, it will behave in essentially the same way as the original brain.*"

[20] "Nanosystems Glossary" (http://e-drexler.com/d/06/00/Nanosystems/glossary/glossary_n.html#Nanotechnology). E-drexler.com. .

[21] "Dorlands Medical Dictionary" (http://web.archive.org/web/20080130031824/http://www.mercksource.com/pp/us/cns/cns_hl_dorlands.jspzQzpgzEzzSzppdocszSzuszSzcommonzSzdorlandszSzdorlandzSzdmd_n_10zPzhtm). Archived from the original (http://

www.mercksource.com/pp/us/cns/cns_hl_dorlands.
jspzQzpgzEzzSzppdocszSzuszSzcommonzSzdorlandszSzdorlandzSzdmd_n_10zPzhtm) on 2008-01-30. .

[22] Lanni C, Lenzken SC, Pascale A, *et al.* (March 2008). "Cognition enhancers between treating and doping the mind". *Pharmacol. Res.* **57** (3): 196–213. doi:10.1016/j.phrs.2008.02.004. PMID 18353672.

[23] Bob Aubrey, *Managing Your Aspirations: Developing Personal Enterprise in the Global Workplace* McGraw-Hill 2010 ISBN 978-0-07-131178-6, page 9

[24] "Longest frozen embryo baby born" (http://news.bbc.co.uk/2/hi/health/4655035.stm). BBC News. 6 July 2005. . Retrieved 14 January 2009.

[25] "Triplets born 13 years apart" (https://www.timesonline.co.uk/article/0,,11069-1682474,00.html). Times Online. 6 July 2005. . Retrieved 24 January 2010.

[26] Kurzweil, Raymond (2005). *The Singularity is Near*. Penguin Books –. ISBN 0-14-303788-9.

[27] Institute on Biotechnology and the Human Future –. *Human "Enhancement"* (http://www.thehumanfuture.org/themes/human_enhancement/background.html). . Retrieved 2007-02-02.

[28] Nick Bostrom (March 2002), "Existential Risks" (http://www.jetpress.org/volume9/risks.html), *Journal of Evolution and Technology*,

[29] Carrico, Dale (2006). *The Politics of Morphological Freedom* (http://amormundi.blogspot.com/2006/08/politics-of-morphological-freedom.html). . Retrieved 2007-01-28.

[30] Georgy S. Levit: The Biosphere and the Noosphere Theories of V. I. Vernadsky and P. Teilhard de Chardin: A Methodological Essay. International Archives on the History of Science/Archives Internationales D'Histoire des Sciences, 50 (144) - 2000: S. 160-176 http://www2.uni-jena.de/biologie/ehh/personal/glevit/Teilhard.pdf

[31] World Transhumanist Association – (2002-2005). *The transhumanist FAQ* (http://www.transhumanism.org/resources/FAQv21.pdf). . Retrieved 2006-08-27.

[32] Hughes, James (2004). *Citizen Cyborg: Why Democratic Societies Must Respond to the Redesigned Human of the Future*. Westview Press. ISBN 0-8133-4198-1.

[33] "Foresight Institute Prize Descriptions and Applications" (http://www.foresight.org/prize/). Foresight Nanotech Institute. . Retrieved 10 April 2011.

[34] Immortality Institute (March 2004). *The Scientific Conquest of Death*. Libros en Red Inc.. pp. 296. ISBN 987-561-135-2.

[35] "Exploring Life Extension" (http://imminst.org/film/). Immortality Institute. 2002-2009. . Retrieved 2010-03-27.

[36] "Immortality Institute" (http://imminst.org/conferences/). Immortality Institute. 2002-2011. . Retrieved 2011-02-12.

[37] Coming to grips with intelligent machines (http://news.cnet.com/Coming-to-grips-with-intelligent-machines/2100-11394_3-6206637.html) Stefanie Olsen, staff writer, CNET, September 7, 2007

[38] Smarter than thou? (http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2006/05/12/BUG9IIMG1V197.DTL), *San Francisco Chronicle*, 12 May 2006

[39] Martin, Douglas (July 11, 2000). "Futurist Known as FM-2030 Is Dead at 69" (http://www.nytimes.com/2000/07/11/us/futurist-known-as-fm-2030-is-dead-at-69.html). The New York Times. . Retrieved 2009-08-25.

[40] "The Genomic Bodhisattva" (http://hplusmagazine.com/2009/09/16/genomic-bodhisattva/). H+ Magazine. 2009-09-16. . Retrieved 2011-11-16.

[41] http://www.nickbostrom.com/papers/converging.pdf Anders Sandberg and Nick Bostrom (2006): Converging Cognitive Enhancements, Ann. N.Y. Acad. Sci. 1093:201-227

[42] http://www.fhi.ox.ac.uk/Reports/2008-3.pdf Anders Sandberg, Nick Bostrom (2008): Whole Brain Emulation: A Roadmap Technical Report #2008-3, Future of Humanity Institute, Oxford University

[43] http://arxiv.org/abs/0810.5515 Toby Ord, Rafaela Hillerbrand, Anders Sandberg (2008): Probing the Improbable: Methodological Challenges for Risks with Low Probabilities and High Stakes

External links

- Transhumanism (http://www.dmoz.org/Society/Future/Transhumanism/) at the Open Directory Project
- Future of Humanity Institute (http://www.fhi.ox.ac.uk/), Oxford University

Article Sources and Contributors

Technological singularity *Source*: http://en.wikipedia.org/w/index.php?oldid=517846932 *Contributors*: "alyosha", ***Ria777, -Majestic-, 0bvious, A13ean, A520, AJ Mars, ALLurGroceries, AQMN, Abductive, Abfackeln, Abyssal, AdamAtlas, AdamRetchless, Adoniscik, Aesir23, Aetheling, Againme, AgarwalSumeet, Ageekgal, Alex Bakharev, Alexanderxerxes, Alextanium, AllGloryToTheHypnotoad, Aloisdimpflmoser, Alta-Snowbird, Amayzes, Amiodarone, Ancheta Wis, Andersmusician, Andfarm, Andresj, Andrewa, Anih, Ankank, Anticipation of a New Lover's Arrival, The, Apeloverage, Arado, Arcadian, Arch dude, Arvindn, Aseld, Ashmoo, Astronaut, Astudent, Athkalani, Athkalani2000, Avsa, AzaToth, B-rat, Babbage, Bass at Central College, Bcjordan, Becritical, Beetstra, Behun, Beland, Benbest, Bensin, Beowulf314159, Bertrow, Bevo, Bfinn, BhaiSaab, Bhny, BigDocOK, Billranton, Bkell, Blahwithit, Bluemask, Bluntyhippo, Bobblewik, Boneheadmx, Bookofjude, Bootstoots, BradBeattie, BrianHoltz, Brtbendele, Bryan Derksen, Bubeck, Buddha Manchester, Byelf2007, CYD, Cabalamat, Cadiomals, Cainxinth, Call me Bubba, Caninedoubletake, Carlaude, Carlodellora, Cedars, CesarB, ChardingLLNL, CharlesGillingham, Che y Marijuana, Ches88, Chris 73, Christine T, Chuffy, Ciphergoth, Clicketyclack, CoderGnome, Codesimian, Colonies Chris, CommonsDelinker, Connelly, ConradPino, Conskeptical, Container guy 257, Corypina, CosineKitty, Cowpriest2, Cptnred, Craig Baker, Crusoe8181, Cyde, Cyfal, Cyp, DCDuring, DJsunkid, DNewhall, Dario D., Darmokandgalad, DataWraith, Datagog, Dave Runger, Davepape, DavidBiesack, DavidCary, Davidlovemore, Dbabbitt, Dbenbenn, Dblandford, Dcjackman, Dcoetzee, Deb, Debresser, Deejaye6, Deepak-nsk, Demerzel, Dendodge, Designate, Desp, Dichotomous, Discospinster, Dmmd123, DoctorDNA, Dougwolens, Dravecky, DreamGuy, Drkjcaserta, Drmies, Dvunkannon, Dysmorodrepanis, Długosz, EagerToddler39, Echuck215, Economicprof, Editor2020, Edward, Eequor, EliezerYudkowsky, Entropy, Ericbg05, Erkleton, Eschatoon, Esoterum, Etimbo, Ettrig, Euyyn, Evanherk, Evercat, Everyking, Everything counts, Ewlyahoocom, Eworrall, Exander, Exidor, Explosiveoxygen, Falcorian, False vacuum, Felicity4711, Ferrelas, Filladdar, Fisherpe, FlashSheridan, Foant, Fordmadoxfraud, Formerly Wu, Fornitm, Fram, Francs2000, Frappyjohn, Furrykef, GGordonWorleyIII, GVnayR, Gaius Cornelius, Galatix27, GameKeeper, Gap9551, Gary King, Gene s, Geni, GeorgeLouis, Giftlite, Gimelgort, Giulioprisco, Glass Sword, Glst2, GoingBatty, Goldkingtut5, GraemeMcRae, GreedyCapitalist, Greeklamb, Greensburger, GregorB, GreyWyvern, Gscshoyru, Gurch, Guy Harris, Gwern, Gwernol, Gzuckier, Hadal, Hans Dunkelberg, Harizotoh9, Harmil, Haukurth, Headbomb, Hillman, Hkhenson, Hmains, Hplus sulpH, Htaccess, Hu, Hu12, Hulagutten, Hybrazil, Hypnosifl, IManOM, IdealisticRealist, Ignitus, Ingolfson, Ipunknown, Irfanh, Irigi, Isaac.rockett, Isobelrosepa, Ivan, J. W. Love, J.delanoy, JCDenton2052, JForget, JaGa, Jackfork, James Doehring, James F Milne, JamesBWatson, Jason Hommel, Jason One, Jawed, Jaxl, Jc37, Jeb, Jhfound`oush jlkdsv njugerhufghew, Jim Henry, Jim1138, JimR, Jimbo Mahoney, Jj137, Jjorr24, Jmnbatista, Jmrowland, Joegoodbud, John D. Croft, JohnSmart, Johnrsax, Jok2000, Jonathan.McGregor.Bethel, Jonathanbethel, Jonnybgoode44, Jorgenev, JoshuaZ, Jpp, Jrincayc, Jrtayloriv, Jtking, Just plain Bill, JzG, KBi, Kaihsu, Kazvorpal, Kelly Ramsey, KenFehling, Kencf0618, Kendrick7, Keraunos, Khazar2, KiTA, Klappspatier, Korath, Krymzon, Kubigula, Kuralyov, Kuru, Kvikram, Kvn8907, Kyleshack2, Kylesnage, L.tak, LA2, Lamro, Larklight, LauriO, Lee Daniel Crocker, Leigh Lundin, Leo44, LesHurv, Lexor, Lfstevens.us, LieAfterLie, Lifeboatpres, Ligulem, LilHelpa, Lir, LongAgedUser, Lordvolton, Loremaster, Lou.weird, Lousyd, Lquilter, Luna Santin, Lvl, Lynndunn, M Alan Kazlev, M2Ys4U, MMBKG, MWithnall, Mandarax, Mantrogo, Manueluribe, Marcelo-Silva, Marcoslee, Maria Nowak, Mark Foskey, Mark Renier, Martarius, Martindo, Martnym, Marudubshinki, Mashford, MasterDirk, Matchory, Maurice Carbonaro, MaxPont, MaxSem, Maxim Razin, Maximus Rex, Maziotis, Meehawl, Metamagician3000, Michael C Price, Michael Hardy, Michael-Zero, Michelle Roberts, Miguel Mayher, Mike Schwartz, Mikker, MilkMiruku, Mindstalk, Minority Report, Miranche, Mitch.mcquoid, MobileDigit, Moly, MoraSique, Morphh, Moxon, Mozkill, MrArt, MrOllie, Mrbill, Mrsnuggless, Mshonle, Mulready, N8o, Nabarry, Nae'blis, Nashhinton, NathanHurst, Natkeeran, NbA, Nectarflowed, Nehrams2020, Neural, NeuronExMachina, Nickptar, Nightscream, Nihil novi, NittyG, Noclevername, Noq, O'Dea, Odx3, Oerjan, OlEnglish, Olathe, OldakQuill, Omeganian, OnePt618, Othniel Kenaz, P4k, PPdd, Painlord2k, PaintedWombat, Pakaran, Palfrey, Palmyrah, Papa November, Papajohnin, Paranoid, Paroswiki, Patstuart, Pauli133, Pcarbonn, Petebertine, Petri Krohn, Petruspennanen, Pevernagie, Phanerozoic, PhilDWraight, PhilHibbs, Philwelch, PhnomPencil, Piano non troppo, Pilotpirx2147, Piotrus, Piperh, Plumbago, Portillo, Postmodernista, PsychoJosh, Psychonaut, Pt, Puckydoodle101, Pwncoreshaman, Pyrop, Qero, QuantumEleven, Quiname, Qworty, R27182818, RA0808, RC Master, RJASE1, Raistlin, Rajah, Ran, Rangoon11, Rapscallion, Ray Van De Walker, Raymond Meredith, Razimantv, Rbarreira, Rdsmith4, Redrocket, Rellis1067, RememberingLife, Renice, Rich Farmbrough, Richard001, Ricosenna, Rjoseph, Rjwilmsi, Rlacy853, Robert Merkel, Robert Skyhawk, Roboshed, Rossnixon, Roux, Rramdin, Ruimsf, Russell Dovey, Rusty2005, Ryururu, SECProto, SHINY TOY GUNS, Saebjorn, Salix alba, Salsb, Sam Hocevar, Sam Korn, Samrolken, SamuelRiv, Sbharris, Sbrantner asst, Sch-u740, Schaefer, Science History, Scochran4, Seantrinityohara, Serinde, Sethmahoney, Shadwstalkr, Shaggorama, ShaunMacPherson, Shawnc, Shii, ShipperS7, SidP, Sigmundur, Silly rabbit, Sinalet, Sinisterstuf, Siroxo, Skier Dude, Skomorokh, Slark, Sleeper99999, Slyguy135, Sm8900, Smokizzy, Sondrawaggoner, SqueakBox, Ssilvers, Star A Star, Stbalbach, Stephen e nelson, Stephenchou0722, Stereoagnostic, SteveChervitzTrutane, Stevenrszabo, Stevietheman, Strebe, Suruena, Surv1v4l1st, Sylve, Symphonia4, Systemizer, Tamfang, Tanner Swett, Tarcieri, Tarotcards, Tassedethe, Tbone, Tdewey, TeleComNasSprVen, Teleolurian, Tempshill, Tgruwell, That Guy, From That Show!, The Anome, The Epopt, The Inedible Bulk, The wub, TheQuaker, Thebt, Theckenlively, Theflyer, Thegreenj, Theomegapoint, Thumperward, Tillman, Tim Chambers, Timc, Timwi, Tired time, Titus III, Tkgd2007, Tobias Wolter, Toby D, Tony Sidaway, Topdownquark, Toussaint, Trackerseal, Transhumanist, Trasel, Tregoweth, Trevorself, Troymacgill, Truthnlove, Tuntable, Twinkie eater91, UKURL, Ugen64, Ukexpat, UltraMagnus, Ultrarob, UnitedStatesian, Urbane Legend, VBGFscJUn3, Vagary, Vald, Vanished user 5zariu3jisj0j4irj, Veemonkamiya, Verbal, Vernorv, Vespristiano, Vicki Rosenzweig, Viriditas, Vnguy, VoX, Vyznev Xnebara, WAS 4.250, WLU, Wangi, Warma, Wavelength, Wayward, Wellspring, Wereon, WhiteDragon, Wiki5d, Wikipelli, WillMall, WilliamKF, Wjfox2005, Wolf530, WookieInHeat, Wperdue, Wumpus3000, Xaosflux, Xensyria, Xideum, Yann, Yannos, Yashgaroth, Ylee, Yono, Yorker, Zachorious, Zaphraud, Zazaban, Zombie Hunter Smurf, Zscout370, Zyryab, Zzyzx11, Иъ Лю Ха, 1171 anonymous edits

Artificial intelligence *Source*: http://en.wikipedia.org/w/index.php?oldid=517926832 *Contributors*: 100110100, 132.204.25.xxx, 172.141.188.xxx, 17Drew, 1dragon, 1exec1, 200.191.188.xxx, A157247, AAAAA, APH, APL, ARC Gritt, AVBAI, AVGavrilov, Abdullahazzam, Abeg92, Academic Challenger, Acerperi, Acrognale, Acroterion, AdSR, Adam Roush, Adamreiswig, AdjustShift, AdultSwim, AgadaUrbanit, Agemoi, AgnosticPreachersKid, Ahoerstemeier, Ai24081983, Aitias, AlGreen00, Alan Rockefeller, Alansohn, Aldux, Alex naish, Alexf, AlistairMcMillan, Allens, Allstarecho, Aloisdimpflmoser, Alsandro, Amareshjoshi, AmiDaniel, Anandcv, Andre Engels, AndrewHZ, Andreworkney, Andy Dingley, Andy Marchbanks, Angr, Aniu, Ankank, Anniepoo, Annonnimus, Antandrus, Anthony Appleyard, Anville, ArielGold, Arne Heise, Arthena, Arthur Rubin, Arthur Smart, ArthurWeasley, ArtificioSapiens, Arvindn, Asbestos, Ashish krazzy, Astrobase36, Atamyrat, Avenged Eightfold, Avery.mabojie, AxelBoldt, Axl, Axon, Aykantspel, AzaToth, Azlan Iqbal, B3virq3b, Baby16, Banes, Banus, Barnaby dawson, BarryList, Barsoomian, Basploeger, BatteryIncluded, Bbewsdirector, Beland, Ben Ben, Benbest, Bender235, Benpryde, Bensin, BertSeghers, Beta Trom, Betacommand, Betterusername, Bforte, Bill52270, Bissinger, Bitsmart, Bjklein, Blackshadow153, Bo Jacoby, Bobblewik, Bobby D. Bryant, Bobianite, Bobo192, Boing! said Zebedee, Boneheadmx, Bongwarrior, Bootedcat, Bootstoots, Borislav, Bornslippy, Bovlb, Bqdemon, Bradgib, Brentdax, Brianjfox, BrightBlackHeaven, Brion VIBBER, BrokenSegue, Brookeweiner, Bryan Derksen, Bryan Seecrets, Bubba2323, Bugone, Burto88, Burzmali, Buster, CO, COMPFUNK2, CRGreathouse, CWenger, Cabiria, Cacuija, Caiaffa, Can't sleep, clown will eat me, CanadianLinuxUser, Capricorn42, CarlHewitt, Casia wyq, Casper2k3, Cassianp, Centrx, Ceyockey, ChangChienFu, Chaosdruid, ChaoticLogic, Charles Gaudette, CharlesC, CharlesGillingham, Cheesefondue, Chessmaniac, Chicarelli, Chocolateboy, Chopchopwhitey, Chris Roy, Chris.urs-o, Chuckino, Chucks91, Chun-hian, Chuq, Ck lostsword, ClaretAsh, Clarityfiend, Coasterlover1994, Cobratom, Coder Dan, CoderGnome, Coffee2theorems, ColinMcMillen, CommodiCast, ConceptExp, Condem, Conskeptical, Conversion script, Coolcatfish, Corpx, CosineKitty, Cremepuff222, Crunchy Numbers, Crzer07, Csörföly D, Curious1i, Curly Turkey, Cvdwalt, CygnusPius, D, D Monack, DARTH SIDIOUS 2, DHN, DVD R W, Damiens.rf, DanMS, Daniel, DanielDemaret, Danim, Daphne A, Dar-Ape, DarkGhost08, Darker Dreams, Darth Chyrsaor, Darth Panda, Darthali, Davespice, Davewild, David D., David Martland, David.Monniaux, DavidBourguignon, DavidCary, Dcoetzee, Ddxc, DeStilaDo, Dee Jay Randall, Dejitarob, Denisarona, DerHexer, Derek Ross, Dessimoz, Devantheryv, Devonmann101, Dheer7c, Dicklyon, Digsdirt, Diogeneselcinico42, Dionyseus, Dirkbb, Disavian, Discordant, Discospinster, Dispenser, Diza, Dlloader, Dlohcierekim, Dmcq, Dmsar, Docu, DonSiano, DonutGuy, DouglasGreen, Dougofborg, DougsTech, Dpbsmith, Dpupek, Dream land2080, Drift chambers, Drmies, Dublinclontarf, Dudesleeper, Dv82matt, Dysprosia, E prosser, ELApro, ELDRAS, ENeville, EPIC MASTER, ERcheck, ESkog, Eastlaw, EdH, Edgar181, Edivorce, Edward, Eggman64, EisenKnoechel, El C, El aprendelenguas, Elassint, Ellmist, Ellywa, Elsendero, Eluchil, Emarus, Emir Arven, Emperorbma, Emptymountains, Emurph, Emuzesto, Eoghan, Epbr123, Erayman64, Erc, Eric Mathews Technology, Eroark, Escientist, Eubulides, Eumolpo, EvanProdromou, Evanh2008, Evanherk, EvelinaB, Evercat, Everyking, Excirial, Eyrian, Eyu100, Ezavarei, Falcon8765, FalconL, Farmer21, Farquaadhnchmn, Fartherred, Fillepa, Finetooth, Finn-Zoltan, Fireboy3015, Flewis, Floquenbeam, Fluffernutter, Foryourinfo, Francob, Francs2000, FrankCostanza, Frans Fowler, Frans-w1, Fraziergeorge122, Frecklefoot, Freek Verkerk, Freemarket, Fribbler, Fricanod, Funandtrvl, Furrykef, Fuzheado, Fvw, GTof, Gabbe, Gadfium, Gaius Cornelius, Galoubet, Gamkiller, Garas, Gareth E Kegg, Gary King, Gdm, Gene s, Gengiskanhg, Geoinline, GerryWolff, Giftlite, Gilliam, Gimmetoo, Gimmetrow, Glacialfox, Glane23, Glen Pepicelli, Glenfarclas, Gmaxwell, Gnome de plume, Gogarburn, Gogo Dodo, Goodnightmush, GraemeL, Grafen, Graham87, Graymornings, GreenReaper, Greensburger, Gregbard, Gregman2, GreyCat, Gridlinked, Grokmoo, Grunt, Guanaco, Guoguo12, Gurch, Gustavo1255, Guðsþegn, Gwernol, Gyrofrog, Gzabers, Habstinat, Hadal, Halmstad, HamburgerRadio, Hamster Sandwich., Harderm, Harmil, Harriv, Harryboyles, Haseo9999, Haymaker, Healeyb, Heldrain, Henrifrischborno, Herbee, HereToHelp, Heron, Herschelkrustofsky, Hervegirod, Hezarfenn, Hfastedge, Hgamboa, Hi878, Hike395, Hobsonlane, Horris, Hpdl, Hthth, Hu, Hu12, Hulagutten, Humanrobo, HumphreyW, Hydrargyrum, Hydrogen Iodide, I already forgot, IRP, IYY, IanElmore, Iceworks, Ignatzmice, Igoldste, Ihavenolife, Ilcmuchas, ImGz, Implements, Imran, Indyfitz, Inego, Insomniak, IntellectToday, Interested, Intrealm, Introgressive, Inwind, Iohannes Animosus, Ioverka, IrishStephen, Isheden, Iskand26, ItsZippy, Ivant, Ixfd64, Iyerakshay, J. Spencer, J.delanoy, J04n, JCAILLAT, JRR Trollkien, Jackol, Jagdeepyadav, Jagginess, Jaibe, Jake11, James childs, Jamyskis, Jan eissfeldt, Jarble, Jared555, Jason Palpatine, Java7837, Javidjamae, Javierito92, Jayjg, Jdzarlino, Jebba, Jeeny, JesseHogan, Jimothytrotter, Jj137, Jkaplan, Jm34harvey, JoeSmack, Joeblakesley, Jogers, Johannes Simon, John Newbury, John Vandenberg, John of Reading, JohnOwens, Johnkoza1992, Johnuniq, Jojit fb, Jon Awbrey, JonRichfield, Jonathan Métillon, Jonrgrover, Jordan123, Jorfer, Joseph Solis in Australia, Josephorourke, Joydurgin, Jpbowen, Jpgordon, Jroudh, Jrtayloriv, Jsun027, Judson, Julian Mendez, JuniorMonkey, Jvoegele, Jwoodger, K.Nevelsteen, KF, Kaldosh, Kane5187, Karada, KarenEdda, Karol Langner, Keidax, KellyCoinGuy, Kevin143, Kevyn, Khalid, Khaydarian, Kimveale, King of Hearts, Kingboyk, Kjellmikal, Klafubra, Kneiphof, Koavf, Kostisl, Koyaanis Qatsi, Kramlovesmovies, Kri, Kukini, Kurowoofwoof111, Kzollman, L Kensington, LFaraone, Lacatosias, Larry laptop, LaserBeams, Lateg, LauriO, Laurusnobilis, Lectonar, LedgendGamer, Lee Daniel Crocker, Leire Sánchez, Lenehey, LeoNomis, Leoneris, Leontolstoy2, Leszek Jańczuk, Levineps, Lewblack, Lexor, Libcub, Liftarn, Liger, Lightmouse, Lilac Soul, Lilinjing cas, Linweizhen, LittleBenW, Livajo, Logperson, Loki en, Looxix, Loremaster, Loxley, Lumos3, Luna Santin, Lylodo, Lynn Wilbur, M, MCTales, MD87, MER-C, MHLU, MIT Trekkie, MJBurrage, MTuffield, Mac, Mac-steele, MacMed, Macduffman, Macilnar, MadSurgeon, Madd4Max, Maghnus, Mailseth, MakeRocketGoNow, Malignedtruth, MangoWong, Mani1, Marc Girod, Marc Venot, Marek69, MarkAb, Marktindal, Markus.Waibel, Martha2000, Martinp, Marudubshinki, Marysunshine, Master Jaken, MasterOfHisOwnDomain, MattBan, Matteh, Matthew Stannard, Maurreen, Mausy5043, Mav, Maver1ck, Maximus Rex, Mayfly may fly, McCart42, McGeddon, Mdd, Mdebets, Me pras, MeekMark, MelbourneStar, Melody, Memming, Mendel, Mercury, Metamagician3000, MiNombreDeGuerra, Micahmn, Michael Fourman, Michael Hardy, Michal Jurosz, MichalJurosz, Mikael Häggström, Mike Schwartz, MikeCapone, MikeLynch, Mild Bill Hiccup, MilesMi, Mindmatrix, Minesweeper, Mintguy, Mmernex, Mmxx, Mneser, Monkee13, Moralis, Mostlymark, Moxon, Mr. Vernon, Mr.Sisgay, MrJones, MrOllie, Mrsolutions, Mrvasin, Mschel, Mschuldt, Mschures, Mudd1, Mullhawk, Muness, Myanw, Myasuda, Myncknm, NCurse, Nabarry, Nabeth, Nach0king, Nanshu, Naohiro19, NapoleonB, Nappy1020, Nayanraut, Ndenison, Neckelmann, NeilN, Neilc, Neko-chan, Netesq, Neverquick, Newkidd11, Nick, Nickj,

Nightscream, Nishkid64, Nistra, Nixdorf, Noctibus, Nondescript, Normxxx, NorrYtt, Novum, Nposs, Nuclear Treason, NuclearWarfare, Nufy8, Nunocordeiro, Nx7000, Obscuranym, Ohconfucius, Olathe, Oldhamlet, Oleg Alexandrov, Olethros, Olinga, Oliver Pereira, Olivier, Olof nord, Onorem, Opelio, Orangemike, Oritnk, Ost316, Ott, OwenX, Owlbuster, Oxwil, Oxymoron83, Pacas, Palace of the Purple Emperor, Paradoctor, Paul A, Pawyilee, Pegua, Peterdjones, PetroKonashevich, Peyre, Pgr94, Phil Boswell, Phileas, Philip Trueman, Pichpich, Piet Delport, Pigsonthewing, Pilotguy, Pinethicket, Piotrus, Pjoef, Pkirlin, Pluke, PluniAlmoni, Poccil, Poiman, Pokrajac, Polocrunch, Poor Yorick, Pooya.babahajyani, Populus, Prakashavinash, Pravdaverita, Preslethe, Prohlep, Prolog, PrometheusX303, Psb777, Pspoulin, Psych2012Joordens, Psychonaut, Public Menace, Puzl bustr, Qartis, Qswitch426, Qwertyus, R. S. Shaw, RCPayne, RJASE1, RK, RabidDeity, Rafael.perez.rosario, Rahuldharmani, Rajah, Ralf Klinkenberg, Rangoon11, Ranjithsutari, Rasmus Faber, Ratiocinate, Reckiz, Recognizance, Reconsider the static, RedHillian, RedWolf, Redaktor, Redvers, Reidgsmith, Remember the dot, Remy B, Renaissancee, Renamed user 3, Rene halle, Rettetast, RexNL, Rgarvage, Rhobite, Rholton, Riccardopoli, Rich Farmbrough, Richard001, RichardKPSun, Richardcavell, Rick Block, Ricvelozo, Rinea, Ripe, Risk one, Rjwilmsi, Rlw, Rnb, Robert Merkel, Robin klein, Roesslerj, Ronz, Rootxploit, Rpmorrow, Rror, Rumping, Ruslik0, Ruud Koot, RyanParis, Ryguasu, Rzwitserloot, S0aasdf2sf, SDC, SWAdair, Sagaciousuk, Saizai, Salamurai, Sam Hocevar, Sam Korn, Sander123, Sango123, Sarnholm, Sbennett4, Sceptre, Schaefer, Schlegel, SchreyP, Science History, Scorpion451, Sdornan, SeanMack, Seaphoto, Searchmaven, Searchme, Seb az86556, Sebaldusadam, Sebastian scha., SecretStory, Selket, Sgunteratparamus.k12.nj.us, Shadow1, Shadowjams, Shaggorama, Shanes, Shannonbonannon, Shanoman, Shenme, Shirik, Shpiget, Shuipzv3, Siddharthsk2000, Sillybilly, Simbara, Simoneau, Sirkad, Sly1993, Smallclone2, SnoopY, Snoutholder, Snoyes, SocratesJedi, Sodium, Sole Soul, SouthernNights, Sparkygravity, Special-T, Spinningobo, Spitfire, Srinivasasha, Staberind, Stardust8212, StarryGrandma, Stefanomione, SteinbDJ, Stephane.magnenat, Stephen G Graham, StephenReed, Stevage, Steve Quinn, Stevertigo, Stoni, Stormie, Stroppolo, Supten, Susvolans, Svick, Sweetness46, Symane, Syncategoremata, Syrthiss, Szeldich, TAnthony, THEN WHO WAS PHONE?, Tabortiger, Taemyr, Taggart Transcontinental, Tailpig, Talon Artaine, Tarotcards, Tassedethe, Taw, Taxisfolder, Taylormas229, Tazmaniacs, Tdewey, Technopat, Tedickey, Teo64x, Terraflorin, ThG, The Anome, The Cunctator, The Divine Fluffalizer, The Evil IP address, The Magnificent Clean-keeper, The Thing That Should Not Be, The Transhumanist (AWB), The world deserves the truth, The wub, TheDoober, TheRanger, TheSix, Thecheesykid, Thede, Themfromspace, Theo Pardilla, Theropod-X, Theyer, Thine Antique Pen, Thiseye, Thomas Kist, Thumperward, Thunderhippo, Thüringer, Tiddly Tom, Tideflat, Tillander, Time for action, Timwi, Titus III, Tkinias, Tkorrovi, Tobias Bergemann, Tobias Kuhn, Toby Bartels, Tokek, Tommy Herbert, Tone, Tony1, Took, Topazxx, Touisiau, Tpbradbury, Tremilux, Trevor MacInnis, Truthnlove, Turk oğlan, TurntableX, TutterMouse, Twexcom, TwoOneTwo, Tzartzam, Ugen64, Una Smith, Uncle Dick, Unknown, Unreal7, Urod, Useight, Utcursch, VSimonian, Varagrawal, Velho, Vesal, Vespine, Vfrias, Vidstige, Vilerage, Virtualerian, Viskonsas, Vivohobson, Voices cray, Vrenator, Vrossi1, Vsmith, W3bj3d1, WBTtheFROG, WMod-NS, Wadeduck, Wafulz, Walter Fritz, Wasell, WaveRunner85, Wavelength, Wdfarmer, WereSpielChequers, Wesleymurphy, Westwood25, Wfructose, WhatisFeelings?, Wiki alf, Wiki-uoft, WikiNing, Wikicolleen, Wikiklrsc, Wikireviewer99, Wikiwikifast, Wile E. Heresiarch, William conway bcc, Witbrock, Wizardist, Wmahan, WojPob, Wookiee cheese, Wyckster, Wyklety, Xensyria, Xklsv, Xobritbabeox10, Xzbobzx, Yakota21, Yankee-Bravo, Yardcock, Yassu66, Ykalyan, YoungFreud, Yoyosocool, Ypetrachenko, Yuckfoo, Yungjibbz, ZENDELBACH, Zaklog, Zapvet, ZeroOne, Zntrip, Zsinj, Zubenelgenubi, Zundark, Zzthex, Zzuuzz, ²¹², Ásgeir IV., Δ, Иъ Лю Ха, 2063 anonymous edits

Outline of artificial intelligence *Source*: http://en.wikipedia.org/w/index.php?oldid=511708309 *Contributors*: Auroranorth, CharlesGillingham, Chrispounds, Clicketyclack, Computertheology, Dancter, Darker Dreams, David Kernow, Equendil, Eric Catoire, Gareth E Kegg, Guillaume2303, Hthth, Hu12, Hulagutten, IDSIAupdate, JamesBWatson, Kumioko (renamed), MadCow257, Michael Hardy, Nexus Seven, Obankston, Paradoctor, Quiddity, Robert Skyhawk, Rwwww, The Transhumanist, The Transhumanist (AWB), Thomas Kist, Wavelength, Woohookitty, 21 anonymous edits

AI-complete *Source*: http://en.wikipedia.org/w/index.php?oldid=517275905 *Contributors*: 0, 144.132.75.xxx, A3 nm, Adamdaley, Auntof6, Beland, Bryan Derksen, Byelf2007, CarlHewitt, Chalst, CharlesGillingham, Chimpex, Darker Dreams, Davehi1, David290, Dcoetzee, Dlrohrer2003, EagerToddler39, Etm3, GregorB, JakeVortex, Jamelan, Karada, Kevin Saff, Last Avenue, Magioladitis, Michael Hardy, MisterHand, Pgr94, Phil Boswell, PhilKnight, Rich Farmbrough, Rizzardi, Rjwilmsi, RobinK, Sophus Bie, Tenured, Tobias Hoevekamp, Twri, WikHead, Yuzz, 21 anonymous edits

Strong AI *Source*: http://en.wikipedia.org/w/index.php?oldid=514271496 *Contributors*: 4th-otaku, AcademyAD, Aderetcentral, Aetheling, Alexey.noskov, Alexios Chouchoulas, Alienus, Alksub, Amallavarapu, Appraiser, Aprock, Arny, Arru, Ashmoo, BD2412, Beetstra, Ben Standeven, Beno1000, BigDwiki, Billycuts, BitStrat, Bjklein, Blaxthos, Boijunk, BostonMA, Britannica, Carpetsmoker, ChaoticLogic, CharlesGillingham, Chris the speller, Christian.B, Conspireagainst, Corge, Cyborg1, DGG, DXL, Dalen talas, Darker Dreams, David290, Davidhere40, Dhart, Dimiter Dobrev, Djayjp, Donhalcon, Drama-kun, Ds13, Duja, Duncan McB, ELApro, ESkog, Edenplib2, Ego White Tray, EightyOne, Espertus, Firetrap9254, FrankCarroll, Furtchet, Gabbe, Gary Lempert, Gioto, GraemeMcRae, Greensburger, Greyscale, Grshiplett, Gubrud, Gwern, Gyll, Gzabers, Harrygao, HatlessAtlas, Henriok, Hgmichna, ILovePlankton, IO Device, IanBailey, Ingolfson, Inimino, Iq100iq100, IronGargoyle, Isarl, J04n, Jaganath, Jaibe, Jake11, Jamelan, Jeb, Johndburger, Jon Awbrey, Kaeslin, KaiAdin, Kaiwen1, Karada, Kerrick Staley, KingPenguin, KoshVorlon, Kostmo, Lamro, Lawyer2b, Leszek Jańczuk, Liftarn, Loadmaster, Lordvolton, Loxley, Luna Santin, Malo, Mange01, Mark Renier, Marudubshinki, MattOates, Matthew Stannard, MegX, Mike Schwartz, Mimigu, Mindbound, Mneser, Mortense, Moses2k, Moxon, Mporter, Ms2ger, N3X15, Nadalle, Nae'blis, Nchoe123, Niceguyedc, Nkf31, Northgrove, Nydas, OlEnglish, Oldhamlet, Paradoctor, Paroswiki, Paul shallard, Pearle, Peterdjones, PetroKonashevich, Pgr94, Poccil, Poochy, Psb777, R'n'B, R001605, Raven Morris, Rich Farmbrough, Rick Norwood, Rjwilmsi, Robert Merkel, Royal Victoria, Ruakh, Ruinia, Rustyfence, Sandstein, Scarlet Lioness, Schaefer, SchreyP, Sevakprime, Shawnc, Skakkle, Skraz, Slarson, Source, StephenReed, Subversive.sound, Tagishsimon, Tarotcards, Tassedethe, Taxa, Tdewey, Tifego, Tim333, Tkorrovi, Tom Edwards, Topbanana, Touisiau, Tuntable, Utopiah, V-Man737, Valeria B. Rayne, Viriditas, WLU, WMod-NS, Wbrameld, WilliamH, Winterst, Yakobbokay, Zophar1, Андрей Романенко, 284 anonymous edits

Progress in artificial intelligence *Source*: http://en.wikipedia.org/w/index.php?oldid=494402090 *Contributors*: BenKovitz, CharlesGillingham, Danim, JanAson, KyleH87, LarryJeff, LeJuifErrant, Mikael Häggström, O.mangold, Pgr94, Rallen7753, Rangoon11, 17 anonymous edits

List of artificial intelligence projects *Source*: http://en.wikipedia.org/w/index.php?oldid=518007610 *Contributors*: AHabbit, Ahpro, Alexander Sommer, Apparition11, Austintate, Back ache, BenKovitz, BenRayfield, ChangChienFu, Codesimian, Conversion script, DARTH SIDIOUS 2, Daniel Brockman, David Eppstein, Defender of torch, Dhart, Donald Albury, Dv82matt, Dysprosia, Eagleblast63, Eclipsed, Funandtrvl, Gadfium, Gronky, Gzabers, Healthwise, IAIndustrie, IO Device, Intrealm, JWSchmidt, Jerryobject, Kerosen, Lumos3, M, Marasmusine, Michalchik, Mneser, Nydas, PatriciaFike, Pearle, Pegua, Pgr94, Polarwind13, Pseudomonas, Quenn, Ralf Klinkenberg, Renamed user 3, Rettetast, Rockanjan, Rwwww, Shermanmonroe, Softnhard.es, StephenReed, Sukiari, TastyPoutine, The Anome, Toms2866, Twexcom, UnitedStatesian, Utopiah, WAS 4.250, X7q, Yoshi555, Yworo, 122 anonymous edits

Applications of artificial intelligence *Source*: http://en.wikipedia.org/w/index.php?oldid=517425898 *Contributors*: 1337pino, 2001:44B8:41A1:A600:305A:BAFA:6261:1FF5, Achowat, Arthur Rubin, Auric, Ayomawdb, Beland, CharlesGillingham, Chase me ladies, I'm the Cavalry, Countchoc, Cpgupta9460, Cresdajv, Csc300student, Elperzon, Fathomer, Gh23, GraffDecors, HaeB, HarlandQPitt, JHP, Jiuguang Wang, Kesara, Landon1980, LeadSongDog, Makecat, Markicus, Mikael Häggström, MilborneOne, PL290, Pgr94, Philip Trueman, Rangoon11, ReformatMe, Rich Farmbrough, Rjwilmsi, Robofish, Soler97, Steel1943, SuperSmashBros.Brawl777, Svick, Telfordbuck, Thine Antique Pen, Tnordlan, Vasiliy Faronov, Wassname, Wavelength, Woohookitty, Xamuel, 47 anonymous edits

Augmented reality *Source*: http://en.wikipedia.org/w/index.php?oldid=518063748 *Contributors*: 22samurai, 2nova, Aaditya 7, Aandelkovic, Aaron.stafford, Abmac, Aeternus, Ahpook, AkuAtaja, Alinoz, Amorrow, Andy Dingley, Anindyasengupta, Anonymous Reviewer, Apotheon, Aprock, Arch2all, Arguru, Arsalank2, Ash, Atkinson 291, AugmentedReality, Averell23, Ayclove, Azwaldo, BD2412, Back ache, BackwardsBoy, BaloneySausage, Barb219, Baschz, Bataviaship, Bdwassom, Beeblebrox, Beebomb, Benjsc, Bjeedit, Bkhn84, Blacksnark, Blairmacintyre, Blumunky, BobKawanaka, Bonadea, Brett.lindberg, Btily, Bumblezellio, Byronknoll, Caltrop, Calvarer, Capricorn42, CaribDigita, CatherineMunro, CharlesC, ChickenChopps, Chowbok, Chr15m, Chris the speller, ChrisAR, Chrismanzione, Ckatz, Clarkdever, Cloudberia, Coasterlover1994, Colinb, Colonies Chris, CommonsDelinker, Compvis, Coyoty, Cst17, Cybercobra, Cybersorceress, Cyclonenim, D0ugparker, DAJF, DARTH SIDIOUS 2, DXBari, Damane, Dandiggins, Danlev, Davepape, Davidleighbeard, Dczarnik, Ddxc, Demosthenes2k8, Dewritech, Diceman, DigitalMediaSage, Dinoflagellate, Disavian, Discospinster, DocWatson42, Dogends, Doyley, Dputig07, Dragice, Drgoldie, Drpickem, Duffhendrickson, Eawentling, Editor999999, Edward, EhJJ, Energy Dome, Eptin, Ettrig, Fabriqate, Fbartolom, Filthy swine, Firsfron, Fluffernutter, Frap, Frehley, Fru1tbat, Fthiess, Fufuchou, Furrykef, Fuzzy, Gap9551, Garyphayes, GeneralCheese, GianluigiCuccureddu, Gillwill2000, Gking92, GliderMaven, Glogger, Gnomatic, Goplat, Gracefool, GraemeL, GregorB, GreySmallHorse, Gruszkad, Gsu eagle 31049, Guinunez, Haakon, Harry, Hasseli, Hata27tr, Hateless, Hcobb, Hebrides, Historicalveritas, Holothurion, Honzibarak, Hthth, IndianGeneralist, Iohannes Animosus, JMyrleFuller, JQF, Jaceek, Jagged 85, Janboonen, Jaranda, Jaystee, Jeffmcneill, JeroenMol, Jeromesandilanico, Jerryobject, Jgazelle, Jgeiger15, Jheald, Jim.henderson, Jlbribeiro, Jmartinezot, Joes8888, JohnOwens, Jonbarril, Jonkerz, Jonpro, Josedavidcuartas, JoshAnish, Joshmedsker, Jrtayloriv, Julief, JumpMan2010, Just Another Dan, Jutta, KBi, KLDavis, KYN, Karol Langner, Karthikndr, Kcpenner, Keastes, Kgrr, Klilidiplomus, Konterfei, Kovos, Kudpung, KungFuMonkey, Kylin.Ma, Leafyplant, Leszek Jańczuk, Lfstevens, LilHelpa, Logical Cowboy, MHSzymczyk, MMeix, Madhugr, Malcolmxl5, Manekchandmehta, Marcok, Marek69, Markdaams, Martarius, Massimo fontana, Mattgroves, Mattwilson0501, Merosonox, Mesler1537, Metaiouser, MichaelMcGuffin, Milkinbags, MindWraith, Mo ainm, Mogism, Mohobo, MorkaisChosen, Mr. Granger, Mr. Strong Bad, Mr3641, Mscwd, Murmur001, Mwarf, N2e, Narkan, Natkeeran, Naturalorganic65, Nbarth, Nealmcb, Neurotropic, Niceguyedc, Nick Number, Nieske, Nnotova, Nogoodatcoding, NovelIntellect, Nuke1st, Ny156uk, Nybiker1, Obsessiveatbest, Ohconfucius, Ohnoitsjamie, Okseduard, Opus 0, PJ Rey, Paddles, PanagosTheOther, Patrick, PaulCutcliffe, Pbre71, PeterQuain, PeterSF49, PhilKnight, Philipjamesbarnes, Piano non troppo, Pieter-Paul, Pietjepuk67, Piglop, Pixelnation, Poko-chibi, Porslap, Prjacoby, Project2501a, PtatozGunaPtate, Puffin, Puhpine, Qluah, Quicorubio, R'n'B, RHaworth, RTC, Raaraan, Radagast83, Ralphybaby, Raphael.Grasset, Rathergood15, Remcovroom, Remisebastien, Remshad, Riverside blue, Rjwilmsi, Robmanson, RockPuppetz, RossTraversSmith, Russell Freeman, RyanTDMC, Sabretooth, Sagaciousuk, Sameboat, Saravask, Schalliol, Schepop, Scmoatti, SeanMack, Serg3d2, Shanes, Shawnc, Shoehorn, Shuipzv3, Skull33, Slubber43, Smb1001, Solphusion, Some jerk on the Internet, SoyYo, Spiffyxd, Squale.lis, Steelbound, Stefanomione, Steven Walling, Strangebuttrue, Subirkumarsingh, SudoGhost, SupperTina, Suryadas, TPIRFanSteve, Tak111, Tassedethe, Te2rx, Technobadger, TedStepanski, Thbb, The Fish, TheDarkKnight42, TheJJJunk, Thelastminute, Thibbs, Thiseye, Tinmith, Tom harrison, TomPreuss, TonyW, Topbanana, Toussaint, Unyoyega, Valueyou, VernoWhitney, Vice regent, Victoriagirl, Victormlgh, Violetriga, Vizbi, Wapcaplet, Wavelength, WayKurat, WhiteOak2006, Wik, Wikimonitorwest, Willifu, Wknight94, Wonchop, Woohookitty, Xaosflux, Yarrik, Yashgaroth, Yjrp, Ynhockey, Ysangkok, ZTebaykina, ZomBGolth, Zundark, نهی سلمان, 850 anonymous edits

List of emerging technologies *Source*: http://en.wikipedia.org/w/index.php?oldid=517734381 *Contributors*: 123465421jhytwretpo98721654, AK456, Ace Frahm, Acroterion, ActPerspective, Agalmic, Akadruid, Altes2009, Antisyzygous, Arthur Rubin, Asaf2, Astazi, Azuris, Ben Ben, Benbest, Bhny, Big B-65, BigDog, Blanchardb, BlueNight, Bluetd, BrianFH, Buzzywuzzy, CanadianLinuxUser, Canoe1967, CharlesC, Chemya, ChildofMidnight, Chowman247, Coby.royer, Cocytus, Courcelles, Cuzzybear, Daniel C, Danim, Deathflyer, Dejasol, Despres, Dobie80,

Dojarca, Dr eng x, EDG161, Elias, Elzair, Epastore, Espoo, Exander, Fraggle81, Francis Tyers, Frap, Funandtrvl, GVnayR, Glane23, Gogo Dodo, Gonzalesre, Gracefool, GrahamP, HairyFotr, Hans Dunkelberg, Havanafreestone, Hibernian, Hirsch.im.wald, Hoyt596, Hulagutten, Illythr, Impossiblepolis, Ipadm, Iridescent, J.delanoy, JCDenton2052, Jamesontai, Jayamohan, Jerryobject, Jjoensuu, John Abbe, John Broughton, John of Reading, Juliancolton, Karthikndr, KellyCoinGuy, Kencf0618, Kigali1, Kjramesh, Korath, Kvongunten, LaFoiblesse, LairepoNite, Legaleagle86, LightSpeed, M2tek, Maghnus, Mange01, Maqayum, Marasmusine, Mark91, Martarius, Materialscientist, Maurice Carbonaro, McSly, Mdann52, Meika, Mikael Häggström, Mikeo, Mindmatrix, Mongrel1979, Moofski, Mramz88, Mtking, MyTuppence, N2e, Nansquared, Nirogard, Oldag07, Oleg Alexandrov, One Salient Oversight, Orangemohawk, Ospalh, Owen Ambur, Paine Ellsworth, Paperclip777, Paradoctor, Poolsuppluclub, Pro crast in a tor, Protious, Psynapz, Quantum Lipids, Queenmomcat, Quinacrine, Railgun88, Rangoon11, Rbrtwjohnson, Reddi, Reinderien, Richard Arthur Norton (1958-), Rilak, Ronz, Rpraveenkum, Samsoncity, Sceak, SchuminWeb, Sejomagno, SemperAnima, Senhuan, Shapeshift1, Shawn Worthington Laser Plasma, ShotmanMaslo, SilkTork, Skater, Sklapro, Slazman999, SlowByte, Sole Soul, Solphusion, Spartan, Spartaz, Spidern, Stuart Morrow, ThatPeskyCommoner, The Enslaver, TheBendster, Themfromspace, ThiagoRuiz, Tideflat, Tim PF, Tom.Reding, Tommy2010, UnitedStatesian, Varnav, Vickopt1, Virtualerian, Visionary77, Vols4L1fe, Vsmith, Waldir, Whitepaw, Will363636, Woken Wanderer, Wolfkeeper, Woohookitty, YUL89YYZ, Yk4ever, Ysangkok, Zazaban, Zodon, 474 anonymous edits

Connectome *Source*: http://en.wikipedia.org/w/index.php?oldid=518048861 *Contributors*: Abhishikt, BD2412, BWP1234, Bdvj1son, Brainiac now, Chris Capoccia, ChrisGualtieri, CopperKettle, Daniel Mietchen, DoriSmith, Felis domestica, Frebule, George Church, Giraffedata, Greensburger, Ingenuity Arts, Joshuav, Kortikal, LilHelpa, Marine-Blue, Markdask, Matstuff, MrPMonday, Nono64, Pahagman, Pascal666, Piscosour00, Rjwilmsi, Robert K S, Snori, Stevage, Superbatfish, Trondarild, Unidesigner, Was a bee, Willat600series, Wkboonec, Yevrah342, 16 anonymous edits

Computational neuroscience *Source*: http://en.wikipedia.org/w/index.php?oldid=512709520 *Contributors*: A314268, APH, ASmartKid, Aaron Schulz, Alex.tan, Alterego, Alv, Andorin, Ariangiovanni, Arne Heise, Ashleyisachild, BUCompNeuro, Bayle Shanks, Benhocking, BertSeghers, Bkroeger, Brainboychik, Cardoso44, Cardosodeoliveira, CasperEACClemence, CesarB, Ceyockey, Chardar, Chealer, Chzz, Cleanwiki, Clicketyclack, CortexSurfer, Cuaxdon, Cyberfay, Database, Davidcofer73, Deodar, Destexhe, Dicklyon, DividedByNegativeZero, Djhbrown, Docu, Dontaskme, DrPhoenix, Duagloth, Ebegoli, Eerosim, Epugachev, ErikDS59, Flynner, Gaelle Desbordes, Gal chechik, Gewaltig, Ha-reed, Hiturik, Hu, James-davis, Jean-Francois Gariepy, Joeyo, Johnkarp, Jon Awbrey, Josephus78, Jwdietrich2, Jwmillerusa, KNakamura, Kernsters, Kghose, Koepsell, Lexor, Lfrench, LittleOldMe, Looie496, Lordvolton, Lova Falk, Male1979, Mange01, Mangst, MartinSpacek, Mattisse, Meduz, Memming, Michael Hardy, Mosquitopsu, N d s f, Necrotranson, Nectarflowed, Neurocompute, Neuromusic, NeuronExMachina, Neuropsychology, Ngoddard, Niarb, Novum, Obankston, Occhanikov, Orvilleduck, Pascal.Tesson, Pgr94, Pillai ajay, Pointer2948, Polarwind13, Psyklic, RDBrown, Rbrette, Rich Farmbrough, Rjanag, Rjwilmsi, Rnwatanabe, Robclewley, Rwalker, Ryly, SamuelRiv, Sardanaphalus, Scott Illini, Sjs2008, Sluox, Smartprogrammer93, SparkOfCreation, Specdude, Srikanth rswamy, Sun Creator, Talanvalash, Teemu08, TjeerdB, Toddphen, Torcini, Transient cns, Trna.michal, Tryptofish, Tzcshl, U+003F, Umar yahaya, UninvitedCompany, Whitelet, Xurtio, Xxxyyyj, Yurigerhard, 151 anonymous edits

Artificial brain *Source*: http://en.wikipedia.org/w/index.php?oldid=508269678 *Contributors*: BitStrat, Brainecology, CarsynG1979, Centrx, Chaosdruid, CharlesGillingham, Colincbn, Colonies Chris, Dragonpyramid, EdBever, Eric Catoire, Eurobas, Frap, Gareth E Kegg, Greenbreen, Iohannes Animosus, Jevansen, Khalid hassani, Khazar, Looie496, Lugia2453, Male1979, Marokwitz, Mattisse, MikeWren, Mr. Stradivarius, Mu, Nicolas1981, Polarwind13, Preslethe, R'n'B, Shanata, Squids and Chips, Tide rolls, Truce m3, Virtualerian, Wikipelli, WilliamH, Yevoc, 34 anonymous edits

Artificial life *Source*: http://en.wikipedia.org/w/index.php?oldid=512129766 *Contributors*: -ts-, AAAAA, Adhemarius, Ahyeek, Ancheta Wis, Aniu, Atomcoeur, Barbalet, BatteryIncluded, Bcameron54, Beetstra, BenRayfield, BloodGrapefruit, Bobby D. Bryant, Bofoc Tagar, Brion VIBBER, Bryan Derksen, CLW, CatherineMunro, Cdocrun, Cedric71, Chaos, CharlesGillingham, Chris the speller, Chris55, Ckatz, Cmdrjameson, Cough, Dan Polansky, David Eppstein, David Latapie, DavidCary, Davidcofer73, Davidhorman, Dbachmann, Demomoer, DerBorg, DerHexer, Dggreen, Discospinster, Draeco, Drpickem, Ds13, EagleOne, El C, Emperorbma, Erauch, Eric Catoire, Erikwithaknotac, Extro, Ferkel, Fheyligh, ForestDim, Francis Tyers, Franksbnetwork, Gaius Cornelius, Graham87, GreenReaper, Guaka, Hajor, Heron, Hingfat, Husky, In ictu oculi, Iota, Ivan Štambuk, JDspeeder1, JLaTondre, Jackobogger, James pic, JiFish, JimmyShelter, Jjmerelo, Joel7687, Jon Awbrey, Jwdietrich2, Kbh3rd, Kenrinaldo, Kenstauffer, Khazar, Kimiko, Kwekubo, Levil, Lexor, Liam Skoda, Ligulem, Loadmaster, Lordvolton, MKFI, Macrakis, MakeRocketGoNow, Marasmusine, Markus.Waibel, Martarius, MattBan, MattOates, Matthew Stannard, Mav, Mdd, Michafaw, Michal Jurosz, Mikael Häggström, Milkbreath, MisfitToys, MrDolomite, MrOllie, Myles325a, N16HTM4R3, NeilN, Newsmare, Nick, Nine Tail Fox, Numsgil, Oddity-, Oliviermichel, Omermar, Onorem, Peruvianllama, Phoenixthebird, Pietro speroni, Pinar, Pjacobi, Predictor, Psb777, Quuxplusone, RainbowCrane, Rankiri, RashmiPatel, Rfl, Rjwilmsi, Robingras, Ronz, RoyBoy, SDC, SaTaMaS, SallyForth123, Sam, Sam Hocevar, Samsara, Seth Manapio, Sina2, Skinsmoke, Slark, Snleo, Spacemonster, Spamburgler, SpikeZOM, Squidonius, Stephenchou0722, Stewartadcock, Svea Kollavainen, Tailpig, Tarcieri, Taxisfolder, Tesfatsion, The Anome, The Transhumanist, TheCoffee, Themfromspace, Thsgrn, Timwi, Tobias Bergemann, Tommy2010, Trovatore, Truthnlove, Wbm1058, Why Not A Duck, Wik, Wilke, William Caputo, William R. Buckley, Zach Winkler, Zbxgscqf, Zeimusu, 191 anonymous edits

Biological neural network *Source*: http://en.wikipedia.org/w/index.php?oldid=499286589 *Contributors*: A314268, AED, Aaron Kauppi, Abmac, Alrik, Ash, Bdworak, BryanD, CALR, Carfro, Clicketyclack, D.Strand, Deodar, Flyhighplato, Jlpinar83, Kariteh, Kku, Lerdsuwa, Lordvolton, Male1979, Mikeblas, Nneonneo, PhnomPencil, R'n'B, Redheylin, Richard001, Rob Hurt, Romanski, RoyBoy, SamuelRiv, Smithfarm, Snowmanmelting, Snowolf, Tabletop, Tarotcards, Tevildo, Thompsma, TjeerdB, Tremilux, Tryptofish, Velho, Wavelength, Whouk, Wingchi, Wmahan, Woodimatic, 38 anonymous edits

Cybernetics *Source*: http://en.wikipedia.org/w/index.php?oldid=517910724 *Contributors*: .:Ajvol:., 1exec1, AbsolutDan, Acroterion, AdiJapan, Aeternus, Alan Liefting, AllanG, AndrewHowse, AndriuZ, Andy Denis, Angela, Apeiron07, Argumzio, Arthena, Artimis Cat, Asukara, Beland, Bhadani, Bobby D. Bryant, Bookuser, BorgQueen, Boris Krassi, Brandelf, Breinbaas, Brona, BrotherGeorge, Bryan Derksen, BryanD, Byelf2007, CanadianLinuxUser, Cbdorsett, Chaosdruid, Chriscf, Ciphergoth, CommonsDelinker, ConceptExp, Conversion script, Daileychwaliboy, DamiaanLVDW, Danim, DaveApter, Davehi1, Deadclever23, Deathphoenix, Denis Diderot, Deodar, Dhcsoul, Djdoobwah, Doctahdrey, Donreed, Doradus, Drjheise, Duke Ganote, EWS23, Ed Poor, Ed Shanken, Ercolev, EricEnfermero, Erkan Yilmaz, Estranom, Fastfission, Fenice, FrancisTyers, Fred Bauder, Fylbecatulous, Fynsnman, Gary Cziko, Giftlite, Gisling, Goldorak, GraemeL, Grivalta, Groupuscule, Guyonthesubway, Haaqfun, Harbingyr, Harriv, Hawdon15, HenkvD, Hithereimdan, Hmains, Howardjp, Hu, Hu12, IMSoP, IanManka, Ike9898, Impact49, J04n, JDspeeder1, JacobTrue, Jayjg, Jefffire, Jheald, Jimmaths, Jleedev, Jm34harvey, Joel Russ, Joffeloff, Jon Awbrey, Jondel, JuJube, Junkfather, Jwdietrich2, Karol Langner, Kelisi, Kenneth M Burke, Kesaloma, Kevin Baas, Klassica, Kocabas, LSmok3, Larry laptop, Lexor, Lightmouse, LilHelpa, Lolzolzolz, Loremaster, Lowellian, Luctor IV, M.e, Magioladitis, Magnusr, ManuelGR, Marcdelm, Martarius, Martian, Mato, Matt B., Maurice Carbonaro, MaxHund, MayaSimFan, Mblumber, Mdd, Metrax, Michael Hardy, MichaelWattam, Mmortal03, Mogadorien, Morenosastoque, Motters, Moveo ergo sum, Mr3641, MrOllie, Mschel, Mxn, NZUlysses, Nagualdesign, Nam H T Rae, Nave.notnilc, NawlinWiki, NeilN, Nejtan, Neuromancien, Nick Green, Nihiltres, Nile, NoiselessJoe, Normxxx, NotQuiteEXPComplete, Oldekop, Omicron18, Ondixonhill, Orderud, Ortolan88, Ott, Paliku, Panoramix, Paul A, Paulpangaro, Pcontrop, Peterdjones, Pgk, Pikolas, Pjrich, Plasticup, Poccil, Pyrsmis, Quiddity, Raiph, Raphaele7, Raven4x4x, Rbudegb, RecoveringAddict, Rejimissac, Rememberway, Ricky81682, Robin klein, Ronz, Rsanz, Sah111-666, Sam Hocevar, Sanguis Sanies, Schakelaar, Scorpion451, Settdigger, SeventyThree, Shizhao, Sholto Maud, Sietse Snel, Sigmundg, Slicky, Sm8900, Snowded, Spawn Man, Sten, Stephenchou0722, Stratocracy, Suryadas, Swedenborg, Tabor, Tassedethe, TastyPoutine, Taxisfolder, Teapeat, Tha Masta, The Cunctator, The Noosphere, The Transhumanist, ThePlaz, Theresa knott, Tomsega, Trclark9, Verbum Veritas, Vlad, Vuo, Warrickball, Wikiborg, Wildman2000, Will Beback, Woohookitty, Wotnow, Xgeom, Zoniedude, Zujine, ZuluPapa5, Александър, 314 anonymous edits

Connectionism *Source*: http://en.wikipedia.org/w/index.php?oldid=516187572 *Contributors*: AKA MBG, AgamemnonZ, Aldux, Andycjp, Asbestos, Boblayton, Brian Sayrs, Brinerustle, Bscotland, Byelf2007, CBM, Cadr, Chaos, Charles Matthews, Christian.B, Cyrus Grisham, DARTH SIDIOUS 2, Deodar, Dicklyon, Djfrost711, DorisH, Dreiche2, Drphilharmonic, Ewlyahoocom, Flyhighplato, Gene s, Gerocus, Givekeeps1109, Gregbard, Gzornenplatz, Helgus, Ignacio Icke, JMBrown, Jonathan.s.kt, Junes, Jwdietrich2, Khazar2, Kku, Kzollman, Lestrade, Lova Falk, Male1979, Mangst, McGeddon, Mdd, Michael Hardy, Mikeblas, Mnaini, Mneser, Mosquitopsu, Mporch, Nesbit, Netlad, Noticket, Paul August, Pgan002, Prari, Quadell, Quota, Reedbeta, Reyk, Rich Farmbrough, RichardF, Robin klein, RoyBoy, Saikiri, Sandman2007, SlipperyN, SparkOfCreation, Spoon!, StephenReed, Thomas Kist, Timwi, Tremilux, Truecobb, Tyrell turing, WIZLOR, Whoiamudunno12, Wknight94, Wmahan, Zeno Gantner, Zinjixmaggir, 139 anonymous edits

Mind uploading *Source*: http://en.wikipedia.org/w/index.php?oldid=515885102 *Contributors*: 1dragon, 2604:2000:FFC0:61:645D:CD7A:4783:A119, A314268, APL, Abyssal, Alberon, Alfvaen, AliveFreeHappy, Alorkoi, Altdotme, Apples grow on pines, Arch dude, Avriette, Babbage, Backupyourbrain, Becritical, Belovedfreak, Ben Wraith, Ben Zealley, Bensiskind, BerserkerBen, Blackmetalbaz, Blair Bonnett, Bradka, BraveGive, Brent Allsop, BrettAllen, Bryan Derksen, Buddha Manchester, CWatchman, Calvin 1998, Canterbury Tail, CardinalDan, Cdc, Cerasitans, Ceroman, ChaosR, CharlesGillingham, Choi9999, Chris Capoccia, Chris the speller, Ciphergoth, Cmdrjameson, Codeczero, Cognita, Crevaner, CultureArchitect, Dagonweb, Dan Polansky, DarksideHalo, Dash323, David Gerard, David Latapie, Deathphoenix, Denis C., Deodar, Des1974, DoctorWho42, Dogman15, Dougweller, Droob, Ds13, EdX20, Edital, EoGuy, Eon fathom, Eschatoon, Ewigekrieg, Excirial, FTW, Falcor84, FartInAirConditioner, Fences and windows, Feral Mutant, Firsfron, Fredrik, Futurist110, Gabbe, Gadfium, Gaius Cornelius, Geneb1955, Glen, Goethean, Goldom, GreatWhiteNortherner, Greensburger, Hans Dunkelberg, Havanafreestone, Hazard-SJ, Heinzi.at, HereToHelp, Horawiki, Hypnosifl, Iceworks, Ilikefood, Intgr, Iron Wallaby, JHunterJ, JWSchmidt, Jakedimare, Jamelan, Jarble, Jobynaralstonfan, Joe2008, Jw2035, Kakashi-sensei, Kejoxen, Kevin chen2003, Kmarinas86, Kudret abi, Larek, Liftarn, Light24bulbs, LilHelpa, LittleHow, Looie496, Lordvolton, Loremaster, Lucaswilkins, MSchmahl, MakeRocketGoNow, Malcolmxl5, Mange01, Marekich, Martarius, Mastertechnician, Matt Duffin, MatthewTStone, Medrate, Meegs, Mercury McKinnon, Mercurywoodrose, Metamagician3000, Mgiganteus1, Michael Hardy, Michaeldsuarez, Miguel Andrade, Mikespedia, Morphh, N16HTM4R3, Neilmckillop, Neslock, Neural.engineering, Nihiltres, Nono64, ONEder Boy, Olathe, Omega132, Orenburg1, Paddles, Pakaran, Pantergraph, Paranoid, Passw0rd, Patrick, Patrick Lucas, Pereant antiburchius, Pflaquerre, Pgptag, Physicistjedi, Pianomikey0, Pictureuploader, Playanaut, Pmrobert49, Posix memalign, Preslethe, PsychoJosh, Pwestep, QuantumEngineer, R'n'B, Rainer Wasserfuhr, Random user 39849958, Reddi, Rjwilmsi, Robin S, Robofish, Rocksanddirt, Ronaldscott, Ryguasu, Rylz, Sanjivdinakar, Sapphic, Saric, Sarkar112, Sasata, Satoku, Scottydude, SelfQ, Shadowjams, Sianta, Sinfonian9986, Skomorokh, Smartyhall, SnowiDragon, SpencerCollins, Startaq, Stephenchou0722, SwedishPsycho, Tabletop, Tamfang, Tango, Tarotcards, Teammm, Teflon Don, Tesscass, The Anome, Theouhiterabbit, TrevorRC, TubularWorld, Twirligig, Tyciol, VernoWhitney, Virtualerian, Vroman, Wapcaplet, Wassname, Wavefront3, Wayiran, Wetwarexpert, Woohookitty, Wowulu, Xaliqen, Yashgaroth, YoungFreud, Zandperl, ZeroOne, Zinger0, Zoe, Ztobor, Zyrath, 491 anonymous edits

Systems science *Source*: http://en.wikipedia.org/w/index.php?oldid=512351515 *Contributors*: Alan Liefting, Altzinn, Asrghasrhiojadrhr, Bacrito, Benking, BryanD, Btphelps, CalRis25, Calmer Waters, Cask05, Cassbeth, Ckatz, CommonsDelinker, Countchoc, Cretog8, Curb Chain, Daviding, Dfrakes, DragonHawk, Dynamoton, ERcheck, Edward, Elfalem, Erkan Yilmaz, Eugene-elgato, Fences and windows, Fenice, Fingerz, Fixaller, GeoW, Headbomb, Hirsch.im.wald, IPSOS, InverseHypercube, Jac16888, Jimmaths, Jj98, Jpbowen, JuanR, Lightmouse, LilHelpa, Mange01, Maximus Rex, Mdd, Michael Hardy, Narayanese, Nbaig, Nolanlove, Oracleofottawa, Paulgiron, Phanerozoic, PhnomPencil, Piano non troppo, Principia, Puceron, RDF-SAS, Redwalker, Rjwilmsi, Ronhjones, SchfiftyThree, Sevenoaks, Shannock9, Sky Attacker, Smee44, Stefanson, Summers, Sustainablefutures2015, Sydbarrett74, Thekingofviruses, Tomsega, Wikijapanwiki, Woohookitty, Zaasmi, Zhenqinli, Zweifel, 53 anonymous edits

Systems biology *Source*: http://en.wikipedia.org/w/index.php?oldid=515772457 *Contributors*: APH, Aeusoes1, Alan Liefting, AlirezaShaneh, Amaher, Amandadawnbesemer, Amirsnik, Andreas td, Arthena, Arthur Rubin, Asadrahman, Aua, Avimaayan2012, Bad Cat, Bamess, BatteryIncluded, Bci2, Benedict Pope, Benjamin Barenblat, Betacommand, Bio-ITWorld, Biochaos, Biophysik, Blueleezard, Boku wa kage, CRGreathouse, CX, Can't sleep, clown will eat me, Cantor, Captain-tucker, Ceolas, Charlenelieu, CharonZ, Ckatz, Claronow, Clayrat, ColinGillespie, Cquan, Crodriguel, D6, DFRussia, DGRichard, Danhash, DanielNuyu, Dirk Hans, Dmb000006, Drgarden, Droyarzun, Duelist135, Edaddison, Edward, Electric sheep, Erick.Antezana, Erkan Yilmaz, Eveillar, FLeader, Favonian, Fences and windows, Fenice, Fletcher04, Foggy29, Fred Stupor Mundi, Fredrik, GabEuro, Garychurchill, Gauravsjbrana, Gcm, Gdrahnier, Ggonnell, Giftlite, Giovannistefano35, GlenBrydon, Gwolfe, Halx, Heisner, Hequba, HexiToFor, IPSOS, IRWolfie-, Insouciantfiend, JRSocInterface, JaGa, Jdegreef, Jethero, Jondel, Jongbhak, Jpbowen, JulioVeraGon, Jwdietrich2, Kane5187, Karthik.raman, Kcordina, Kieran Mace, KirbyRandolf, Kku, Klenod, Klipkow, Lauranrg, Lenov, Letranova, Lexor, Lilia Alberghina, Linkman21, Listmeister, Lkathmann, Massbiotech, Mbadri, Mdd, Meters, Michael Fourman, Michael Hardy, Miguel Andrade, MikeHucka, Mkotl, Mkuiper, Mmxx, Mobashirgenome, Mohawkjohn, Molelect, MrOllie, N2e, NBeale, NIH Media, Narayanese, Natelewis, NavarroJ, Nbaliga, Neilbeach, Nemenman, Netsnipe, Nick Green, Nono64, O RLY?, Oddleik, Ohnoitsjamie, Ombudsman, Opertinicy, OrcaMorgan, Patho, PaulGarner, Pgr94, Pkahlem, PointOfPresence, Pvosta, Quarl, RDBrown, Rajah, Reggiebird, Rich Farmbrough, Rjwilmsi, Robnpov, Rvencio, Rwcitek, Satish.vammi, SeanAhern, SeeGee, Senu, Seuss01, Sholto Maud, Skittleys, Slon02, Smythph, Srlasky, Steinsky, Stewartadcock, Strife911, Sunur7, Svick, Synthetic Biologist, Tagishsimon, Template namespace initialisation script, The Bald Russian, TheoThompson, Thomas81, Thorwald, Touchstone42, Triamus, U+003F, Unauthorised Immunophysicist, Urselius, Vangos, Versus22, Vonkje, WLU, Waltpohl, Wavelength, Whosasking, Xeaa, Zargulon, Zlite, Zoicon5, Zuck3434, سعی, 426 anonymous edits

Biology *Source*: http://en.wikipedia.org/w/index.php?oldid=516395018 *Contributors*: (jarbarf), -- April, 000n, 068152, 129.174.166.xxx, 1297, 168..., 19.168, 203.33.146.xxx, 28421u2232nfenfcenc, 62.42.63.xxx, 64.12.106.xxx, 808freakpopfreak808, A-giau, A1kmm, A3RO, ACE444, ALE!, APH, Abc518, Abdullais4u, Accurizer, Acerperi, Adam Bishop, Adam Retchless, AdamRetchless, Adambro, Adashiel, Adenosine, Aeconley, Agathman, Ahoerstemeier, Aitias, Akamad, Akanemoto, Alan Liefting, Alansohn, Ale jrb, Alex groos, Alex.tan, AlexDenney, Alexius08, AlexiusHoratius, Ali C 123, Alopex, Alphachimp, Alreen32, Altermike, Altruistic Egotist, Amaltheus, Amog, Ancheta Wis, Andonic, Andre Engels, Andrewlp1991, Andy85719, Angela, Angr, Animum, Annabanana 001, Anonnn123, Anonymous editor, Anonymous346, Antandrus, Anthere, Anticent, Anypodetos, Aphaia, Archillie, ArglebargleIV, ArielGold, Arjuna316, Arkuat, Articleeditor18, Ascorbic, Asenine, AshLin, Astropithicus, Athaenara, Atif.t2, Aua, Audacity, Autonova, Average Earthman, Awickert, AxelBoldt, Ayxiao, Azcolvin429, Ba'Gamnan, Baa, Backslash Forwardslash, Bakilas, Balaam42, Ballista, Banes, BarretB, Barryob, Bart133, Bassbonerocks, BatteryIncluded, Bbowenjr, Beaux182, Beland, Ben4mn, Bensaccount, Bfigura's puppy, Bfjf, Bibliomaniac15, Big Bird, Big Brother 1984, Bigtom5, Bill Nye the wheelin' guy, Billydabox, Bkonrad, BlaBlaBlaBla9, Blade1237, BlairRocksHard, Blake-, Blakegripling ph, Blanchardb, Blizzardbrad2, BlueDevil, Bluejeanbabix0x, Bluemask, Bmeguru, Bob, Bobert93bobert, Bobjob455, Bobo192, Bobozz, Bobvila2, Bodnotbod, Bon 062, Bonadea, Bongwarrior, BonsaiViking, Boomin0024, Born in 1993, Brandon, Bremerenator, Brian Crawford, Brian0918, Brion VIBBER, Brona, BrotherGeorge, Bryan Derksen, Bryan Fedner, Btarlow, Bubba hotep, Bucephalus, Bucketsofg, Bueller 007, Burntsauce, CALR, CIreland, COMPFUNK2, CTF83!, Cab91, Cacycle, Cadiomals, Caiaffa, Calor, Camembert, Can't sleep, clown will eat me, CanadianLinuxUser, CanisRufus, Canthusus, Capricorn42, CardinalDan, Carinemily, Carmen56, Cartiod, Castro92, Causa sui, Cbilinski, Cenarium, Charleca, CharlesC, Charley white, CharlotteWebb, Chas zzz brown, Cheesycheesus, ChemGardener, Chick Bowen, Chillyhot8, Chocho123, Chris the speller, Chrislk02, Christian List, Christopher Parham, Chriswiki, Church of emacs, Chzz, Ciceronl, Classic 58, Claytonwins, Closedmouth, CloudNine, Cnorton10, Cnsnmrt, Coemgenus, Coffee, ColdFeet, Cometstyles, ConfuciusOrnis, Constance182, Cosmi, Cp111, Cpl Syx, Crackfox, Crapper123456, Crazyaboutbio, Creeperdude, Crookshankz227, Crzer07, Cskin, Curps, Curtmack, Cuvtixo, Cwmhiraeth, Cxz111, Cyberied, Cyrus XIII, Czforums, DBishop1984, DVD R W, Daandyman, Daen, Daf, Dancter, Danger, Danielkueh, Danimoth, Danski14, Dark Samus, DarkLordofSith, Darkmaster2004, Darthgriz98, Darthvader102938, Daven200520, Davet002, David0811, DavidLevinson, Davidloveshalo3, Davvvz0r, Daycd, Dbaird31919bnerq, Dd 8630, DeadEyeArrow, Deadcorpse, Dejvid, Dekaels, Dekisugi, Delbert Grady, Delirium, Delldot, Denelson83, Dennis Bratland, Densomate, Deor, DerHexer, Derelk, Dethme0w, Deviathan, Dhp1080, Dialectric, Diamondbd, Dico Calingal, Digdug41, Discospinster, DividingAmoeba, Dkudel1, Dmerrill, Doc Tropics, Doc glasgow, Docboat, Doctorage, Doctoroxenbriery, Docu, Donarreiskoffer, Doniago, Doszika, Douchecock, Doulos Christos, Download, Dr.K., DragonflySixtyseven, Dreadstar, Dumelow, Dureo, Dycedarg, Dylan620, Dysprosia, EJF, ERcheck, ESkog, EWS23, EarthPerson, Earthship27123, Eboireau, Ebonyskye, Eclecticology, EconoPhysicist, Ed Poor, Edgar181, Edgars2007, EditGenius, Eequor, Egil, EivindJ, Eiyuu Kou, Ejosse1, Eksxcrew, El C, El aprendelenguas, Elassint, Eleassar, Elimisteve, Elm-39, Emble64, Emrgnc, Enviroboy, Epastore, Epbr123, Eperotao, Epf, Equilibrial, Er Komandante, Erdigenc, Eric-Wester, Eric111111, Erik9, Erxnmedia, Esanchez7587, Escape Orbit, EscapingLife, Ettrig, EugeneZelenko, EvelinaB, EverSince, Evercat, Everyking, Everythingman, Evolver, Evy Surender, Ezhiki, Fagopyrum, Falcon8765, Faradayplank, Farosdaughter, Fastily, Fbc215, FetchcommsAWB, Fieldday-sunday, Figma, Filipe1997, FireBrandon, Fireyair, Fl, Flatterworld, Flauto Dolce, Flewis, Florian Blaschke, Flubeca, Flyguy649, Fmehdi, Fnar, Fokion, Foxj, Fragmaster12345, Frap, Fred Bauder, Fredo, Freedomlinux, FreplySpang, Freyr, Friginator, FrummerThanThou, Fuzheado, Fyver528, Fyyer, G. Campbell, G3pro, G4p3, GDonato, GSlicer, Gabbe, Gabboudi, Gabyguts, Gaelen S., Gaius Cornelius, Galoubet, Gamewizard71, Gareth Owen, Gary King, Gary123, Gary2863, Gdavidp, Gene.arboit, Gengiskanhg, Geniac, Gerrish, Gerwinjohn 91, Ghepeu, GhostofSuperslum, Ghyll, Giftlite, Gilliam, GiollaUidir, Giorgioz, Glen, Glenmin, Glenn, Globalsolidarity, Glossary, Gniniv, Go for it!, Gogo Dodo, GoneAwayNowAndRetired, Good Olfactory, Graham87, Grasdal, Greyhood, GrooveDog, Gryphn, Gscshoyru, Guanaco, Guettarda, Gugaua, Gunlak, Gurch, Guy Peters, Gwernol, HRHITTER3000, HTML, Haakon, Hadal, Hallenrm, Halmstad, HappyInGeneral, Hard Raspy Sci, Hardyplants, Harry491, Harryboyles, Harrystevens, Hatch68, Havfunonline2, Hdt83, Healthwise, Heegoop, Helenginn, Heron, Heybutch, Hmrox, Hohanyao, Hotties92, Hydrogen Iodide, Hydrorunner, Hyfzyz, I am not a dog, I dream of horses, II MusLiM HyBRiD II, IRP, Iamanerd2215, Iant, Icestorm815, Icseaturtles, Ignitus, Ike9898, Ilovebrains, Imrllllycool, Ioverka, Iridescent, IronChris, Island, It Is Me Here, Itoldusi, Itsmine, Ixfd64, J. Ablitt, J.delanoy, J04n, J4tt, JCO312, JForget, JLaTondre, JNW, JRWalko, JUBALCAIN, JWSchmidt, JackOlais, Jackblackhead, Jackelfive, Jackol, Jagged 85, Jahnavisatyan, Jake Wartenberg, Jake609164, Jamburger, JamesHilt62, Jamesofur, Jamesontai, Jamesooders, JarlaxleArtemis, Jarry1250, JavierMC, Jayden54, Jayjg, Jcarroll, Jean Sibelius, Jecar, Jediangelo, Jeff G., Jeffrey Mall, JemGage, Jgritz, Jh12, Jim62sch, Jj137, Jjacobse, Jmabel, Jmanigold, Joannamasel, JoanneB, Jobseeker-us, Joconnol, John Alliage Morales, John Fader, John254, JohnCD, JohnOwens, JohnWittle, Johnbrownsbody, Johntex, Johnuniq, JonHarder, Jonadin93, Jorunn, Jose Ramos, Jose77, Josephcunningham, Josh Grosse, JoshuaZ, Joymmart, Joyous!, Jpgordon, Jredmond, Juliancolton, Jumbuck, Junglecat, Jusdafax, Jusjih, Just Another Victim Of The Ambient Morality, Just plain Bill, Jvbishop, K, KCinDC, KJS77, Kaarel, Kaldari, Kaleal92, Kaleb.G, Kandar, Kariteh, Karlwick, Kasonjimjk, Kateshortforbob, Kavanagh21, Kbrooks552, Kdbm&mk, Keegan, KeepItClean, Keilana, Keithylane, Kelvinc, Kennethduncan, Kenny sh, Kikika, Killervogel5, KindGoat, Kingpin13, Kkonnichiwa, Kku, Kleinhev, KnightRider, KnowledgeOfSelf, Knowledgeum, Koavf, Koolokamba, Koyaanis Qatsi, Kreemy, Krellis, Krich, Kroova, Kukini, Kupirijo, Kuru, Kyoya23, KyraVixen, LC, LOL, Lam-ang, Landon1980, Langer13, Larapsodia, Leafyplant, Leannaknight, LearnMore, LeaveSleaves, Lee Bailey, Legoktm, LeighvsOptimvsMaximvs, Leonard^Bloom, Lesnail, Leuko, Leveni, Levineps, LexCorp, Lexor, Liamstone, LibLord, Licor, Lil harry g, LinguistAtLarge, Lir, LittleHow, Llull, Logan baum, Logicien, LonelyBeacon, Long Live Life, Loodog, Looie496, Lorangriel, Lord of Cocytus, Lucanos, Luigi-ish, Luk, Lumos3, Luna Santin, M!ll!0n4!r3, M4701, MBisanz, MER-C, MPerel, MZMcBride, Macarenaman, Macedonian, Macellarius, Magnus Manske, Makuvex001, Malhonen, Mandolinface, Mani1, ManlyMan94, Mann jess, Mapetite526, MarSch, Marek Mazurkiewicz, Marek69, Marijuanaboy, Marj Tiefert, Mark J, MarkSutton, Markhurd, Markjoseph125, Marnanel, MarsRover, Marshman, Martin451, Master shepherd, Math Champion, Maturant, Maurreen, Mav, Maxim, Maximillion Pegasus, Maximus Rex, Maxis ftw, Mayumashu, Mboverload, McDogm, Mccready, Mdd, Mdebets, Mdw123, Mehrunes Dagon, Melloss, Memotype, Meno25, Mentifisto, Merlion444, Methcub, Metju, Michael H 34, Michaelkemp, Midgrid, Migetman12345, Mike Dillon, Mike6271, Miquonranger03, Mistermath1, Miyagawa, Mmmevolution, Modemac, Moe Epsilon, Mooseychicken, Moreschi, Moumine, Mr. Billion, MrB, MrFacchin, MrKIA11, MrOllie, MrZap, MsDivagin, Mshecket, Mustafarox, Mustelidae, Muya, Mwanner, Mweites, Mwilso24, Mxn, Myanw, N5iln, NRA2113, Nagy, Nakon, Nameneko, Narayanese, NatureA16, NawlinWiki, Nbarth, Nburden, Nebiros, Nehwyn, NeilN, Nepenthes, Neptune5000, Netesq, Netkinetic, Netoholic, Neutrality, Neverquick, NewbieDoo, Nhf1918, Niborx, Nickptar, Nihiltres, Nikola Smolenski, Nikolaydimitrov, Nilmerg, Nivix, Nixeagle, Node ue, Nopetro, Norm, North Shoreman, Northamerica1000, Notheruser, Nov ialiste, Nsaa, Nubulatorpwnt, NuclearWarfare, Numbo3, Ocatecir, Octavian history, OlEnglish, Olivier, Omegatron, Omglolrofl, Omicronpersei8, Omnipaedista, Ontopic, Opelio, Orangemarlin, OspreyPL, Ost316, Otolemur crassicaudatus, Outriggr, Oxymoron83, PDH, PIrish, Pakaran, Palaotottkaka101, Palkia1992, Panmove, Panoptical, Panton 1980, Paranomia, Parslad, Passw0rd, Pathoschild, Paul August, Peak, Pengo, Pentasyllabic, Pepsidrinka, Perfectlover, Perhols, Peruvianllama, Peskasker, Peterlin, Petri Krohn, Pgk, Phantomsteve, PhilKnight, Photonikonman, Piano non troppo, Picosaur, Pilotguy, Pimjuicep, Pinethicket, Pinkadelica, Pip2andahalf, Pir, Pirateperson, Pjlmac, Plumbago, Pmrich, Polluxian, Polyhister, Polymerbringer, Polyvios, Ponyo, Poopoopeepee000000, Porterjoh, Postoak, Pphilippos, PranksterTurtle, PrestonH, Professor Chaplin, Proofreader77, Puchiko, Quadell, QuartierLatin1968, Quinsareth, Quintote, Quizkajer, R. S. Shaw, RFerreira, RJHall, RJaguar3, RTC, Radon210, Ragesoss, Raimburch, Ralesk, Randallin, RandomP, Raven4x4x, Reddi, Redvers, Regibox, Reilly, RekishiEJ, Remi0o, RexNL, Rey sidney, Reywas92, Rhobite, Riana, Rich Farmbrough, Rich257, RichAromas, Richard001, RichardF, Richman, Riekuh, Rifleman 82, Riomack, Riotrocket8676, Rjd0060, Rje, Rjwilmsi, Rkr1991, Robert A. Mitchell, RockMagnetist, Ron-white, Ronhjones, Ronz, Rory096, Roux, RoyBoy, Royalguard11, Rrburke, Rror, Rsm99833, Rsrikanth05, Rubi yakuta, Rudiverspoor, Rupesh.ravi, RxS, RyanCross, Rymosquito, Ryulong, S, S h i v a (Visnu), S8rchic13, SCEhardt, SFC9394, ST47, SU Linguist, Sacramentis, Saeed.Veradi, Salmar, Salsa Shark, Sam Korn, Samlyn.josfyn, Samsara, Sanbeg, Sanja565658, SaveTheWhales, Scarian, Sceptre, SchfiftyThree, Schissel, Schwnj, Science4sail, Scipius, Scott361, ScryerFallens95, Sdornan, Secretlondon, Selket, Sengkang, Seqsea, Seraphim, Seraphimblade, Shadowjams, Shalom Yechiel, Shanel, Shanes, Shannon bohle, ShaunES, Sherip23, Shiconia, Shizhao, Shlomke, Shoaib, Shoemaker's Holiday, Shoeofdeath, Shyamal, SimonP, Sionnach1, Sirtrebuchet, Skinny McGee, Skitzncute, Skysmith, Slakr, Slicing, Snalwibma, Snowolf, Snoyes, Snuffengluffen, Someone else, SpaceFlight89, Spartan-James, Spellcast, Spliffy, Sportsbang, Sseedaf, Stardust8212, Steel, Stefeyboy, Steinsky, Stemonitis, Stephen Gilbert, Stephenb, Sternmusik, SteveW, Steveking 89, Steven Zhang, Stevenfruitsmaak, Stevertigo, Stickee, Stillnotelf, Sting-fr, Studentboy8, StudyAndBeWise, Stwalkerster, Suffieldlax24, Suffusion of Yellow, SupaStarGirl, Syrthiss, THEN WHO WAS PHONE?, THNswimmer11, TJVIRAR, TUF-KAT, Tadas12, Taral, Tarquin, TastyPoutine, Taymusic, Te24409nsp, Tedius Zanarukando, Texture, Thadius856AWB, The 92nd Revolutionist, The Anome, The Thing That Should Not Be, The Transhumanist, The Transhumanist (AWB), The71, TheAlphaWolf, TheFeds, TheFox3, TheGerm, TheGunn, TheNewPhobia, TheProf07, TheSeer, Themfromspace, Theresa knott, Thingg, Think outside the box, Thkim75, Thomas Larsen, Tide rolls, Tigershrike, Tiggyp11, Tim Q. Wells, TimVickers, Timir2, Timothy Clemans, Titoxd, Tjunier, Tktktk, Tobby72, Tomi, Tomisti, Tpbradbury, Traroth, TreasuryTag, Trichodinamitra, True Pagan Warrior, Trusilver, Tslocum, Turnstep, Tv316, Twodadds, Twoeyedhuman, U&ME WE COOL, Ukexpat, Ularevalo98, Universal1300, Unyoyega, Urbanhype, User A1, UtherSRG, Van helsing, Vanished User 4517, Vary, VashiDonsk, Ve4ernik, Venu62, Versus22, Viriditas, Vishnupstvm, Vivio Testarossa, Vlmastra, VolatileChemical, Vsmith, WBardwin, WCWA, WHeimbigner, WadeSimMiser, Wakandas black panther, Wakka, Walton One, Wanderer57, Wasell, Washington irving, WatermelonPotion, Wavehunter, Wavelength, WaysToEscape, Weeliljimmy, Werdan7, WhiteRhino, Wiki alf, WikiDisambiguation,

WikiPotter, Wikichickenlol, Wikieditor06, WikipedianMarlith, Wikiskimmer, WillColeda, Williamb, Willking1979, Wimt, Witchzilla, Wmahan, Wolfkeeper, Wolfrock, Wompa99, Work permit, X!, Xcentaur, Xdeadpoetsocietyx, Xiahou, Xiaphias, Xp54321, Yahel Guhan, Yamamoto Ichiro, YellowMonkey, Yerpo, Yhkhoo, Yidisheryid, Yoninah, YourEyesOnly, Youssefsan, Yuanchosaan, Zach296, Zappernapper, Zazaban, Zhou Yu, Zomno, Ztbbq, Zylosumnersl, احمد-نجيب-بياني-لابراهيمخ, 2407 anonymous edits

Transhumanism *Source*: http://en.wikipedia.org/w/index.php?oldid=515641501 *Contributors*: "alyosha", 1dragon, A.Z., AJHalliwell, AManWithNoPlan, AbbaIkea2010, Abune, Acclark, Acidsaturation, Acs1969, Action potential, Adbatstone, AdoniCtistai, AdultSwim, Afitillidie13, Agustinaldo, Ahoerstemeier, Ahruman, Aircorn, Airplaneman, Alexanderxerxes, Alexlange, Alfredstreet, Alias Flood, Altdotme, Amonloki, Anaraug, Andrew Levine, Andycjp, Andypandy.UK, Angela, Angr, Ansaheli, Anville, Aodhdubh, Arch dude, Archelon, Arosophos, Astudent, Atticmouse, Ausir, Avriette, Axl, AzaToth, Babbage, BarryWalton, Barsoomian, Bcorr, Belovedfreak, BenB4, BenHyink, Benbest, Bernard Marx, Bfigura's puppy, Billinghurst, Biruitorul, Bjklein, BlackestFire1, Blanchette, BlarghHgralb, Blobglob, BoNoMoJo (old), Bobblewik, Bobrayner, BokicaK, Bookofjude, Brad101, Brandmeister, Brandmeister (old), Brian0918, Brianhe, Brighterorange, Brockert, Bryan Derksen, Buchanan-Hermit, Bumhoolery, Bureb62, CJGB, CNicol, CT109, CalebNoble, Can't sleep, clown will eat me, Cardsplayer4life, Catskul, Causa sui, Chapmaning, ChloeD, Chowbok, Chris the speller, Christopher Sherman, Chrontius, Codeczero, Colonel Warden, Common Man, CommonsDelinker, Connection, ConradPino, Conversion script, Cooltrainer Hugh, CoramVobis, Cunya, CyberSkull, Cyberwraith81, Cyde, D6, Dacoutts, Dagonweb, Dalf, Dariodario, Darkmusashi, Databorg, David Gerard, DavidDAT, Dbachmann, Dcoetzee, Deathphoenix, Dekimasu, Denisarona, Deodar, Deposuit, Derktar, Despres, Deviceminder, Dhart, Digitalme, Discospinster, Diza, Dnagod, Dougweller, Dpotter, Dpr, Dr.K., DrDisco, Dreadstar, Dreampsy, DriveMySol, Dshallard, Ducknish, Dustin1122, EagerToddler39, EdH, Eduen, Edward, EdwardSmith, Eequor, ElKevbo, ElizaBarrington, Erc, ErgoSum88, Erik, Ernie 76, Ersus, EuroTom, EverGreg, Evil saltine, Evolauxia, Ewigekrieg, Explosiveoxygen, Factorylad, Fang 23, Fang Aili, Fangz, Fastfission, FayssalF, FeanorStar7, Fearwig, Fenice, Ferdinand Pienaar, Fjarlq, Flammifer, FlyingToaster, Fordmadoxfraud, Former user, Fractalmichel, FrancisTyers, FrummerThanThou, FullMetal Falcon, Gabbe, Galizur, GangofOne, Gap9551, Gary King, Gdr, Gdvorsky, GeoGreg, Gertie, Ghetteaux, Ghodan, Ghostinthewiki, Gimmetoo, Ginstrom, Glen, Globjulia, Gloriamarie, GoodCop, GraemeMcRae, Graham87, Grant76, Gregbard, GregorB, Griffinjns, Gtrmp, HaJa101, Haakon, Hallows AG, Harold Lockworth, Hede2000, Hephaestos, HereToHelp, Heron, Herostratus, HighPriest15, Hkhenson, Hu, Human.v2.0, Huon, Huwmanbeing, IRWolfie-, Ian.thomson, Ianeveritt, Ibadibam, Icairns, Illuminatiscott, Ingolfson, Invisifan, Iridescent, Isaac, Isolani, Itsmejudith, Ivan Štambuk, JRM, JRR Trollkien, JaGa, JakeVortex, James Knevitt, Jamesontai, JamieS93, Jarble, Jason One, Jason Palpatine, Jauhienij, Jhamez84, Jimbo787, Jimbº Wales, Jkeene, Jkelly, Jlittlet, JoanneB, JohnnyMrNinja, Johntex, Jonathanbethel, Jonicus, Jonnybgoode44, JoshAlfred, JoshuaZ, Jtbelliott, Jtking, Juhaz, Jules.lt, Jvpwiki, Jwclement, K. the Surveyor, KBi, Kakofonous, Kanzure, Kashami, Katherine, Kevinfreels, Khorshid, Kilburn London, Kintetsubuffalo, Kiruba catherine, Koavf, Kozuch, Krick, Kris Schnee, Kross, Ksd5, Ktan, Kubigula, Kungfuadam, Kusma, Kyle Barbour, Kyorosuke, L Trezise, La goutte de pluie, Lambyte, Lapaz, LarryJeff, Layona1, Leandrod, Lee Daniel Crocker, Leif, Lemmey, Leon..., Leonard^Bloom, Lestatdelc, Leuko, Lexicon, Lightmouse, Ligulem, LilHelpa, LordZarglif555, Loremaster, Lorkki, Lucidish, Lynndunn, MER-C, Macterra, Mani1, Manicjedi, Marcus Beyer, Mareino, Marudubshinki, MasterOfHisOwnDomain, Mathonius, Matthew c, Max rspct, Maziotis, Meelar, Meeso, Mel Etitis, Melamed katz, Meneth, Metamagician3000, Michael Devore, Michael Hardy, Michaelbusch, Michelferrari, Mikael Häggström, Mike2050, Mild Bill Hiccup, Miller77, Mindspillage, Mindstalk, Miotroyo, Miracle Pen, Miranda.m.martin, Misarxist, MisfitToys, Mjk2357, Mlorrey, Modulatum, Moocats, Mordicai, Morphh, Mozzerati, Mr. Lefty, Muller504, Mysekurity, NaderChehab, Nashhinton, Natalie West, Natasha Vita-More, NawlinWiki, Nfleming, Nick Number, Nick90210, NickStoyanov92, Nickptar, Nightscream, Nikkimaria, Niroht, Nitya Dharma, Nk.sheridan, Noclevername, Noel Streatfield, OGoncho, OI1A-Mikel Portu, Omegatron, Omneo, Omphaloscope, Orangemike, OrbiliusMagister, Ost316, Otashiro, Othniel Kenaz, Ott, Ottre, Oz1sej, PDH, Paddles, Painlord2k, Paleorthid, Paranoid, Paranomia, Patriarch, Pereant antiburchius, Peruvianllama, Petebertine, Petri Krohn, Pgan002, Pgptag, Ph.eyes, Philosomystic, Phlebas, Pichpich, Piotrus, Pliiganto, Plumbago, Pol098, Polyesterthought, Poor Yorick, Portillo, Postdlf, Powell.0, PowerPatrick, Protious, PsychoJosh, Punainen Nörtti, Pydos, Pyrop, RDF, Ran4, Rangoon11, Raul654, Reaverdrop, RedSpruce, RememberingLife, RevanX, Rich Farmbrough, Richard001, Rjwilmsi, RobertG, Rolinator, Ronebofh, Ronline, RookZERO, RoyBoy, RucasHost, Ruimsf, Rursus, Ryulong, SFairchild, Salsa Shark, Sam Hocevar, Sam Spade, Sampi, Samsara, Samuel Blanning, SamuelRiv, SandyGeorgia, Sango123, Sannse, Savidan, Schaefer, ScienceApologist, ScienceLion, Scohoust, Sean Parmelee, Sethmahoney, ShamelessAngel, Shanoman, Shsilver, SimonD, SimonP, Sionus, Sir Paul, SirGrant, Sjc, Skakkle, Skomorokh, SlimVirgin, SliverTissue, Snappy, Snigbrook, SonOfNothing, SpaceTycoon, Spacenookie, Splash, StN, Stargate70, Steinsky, Stephenchou0722, Str1977, Streetlightspark, Strom, Summer Song, Sundar, Surv1v4l1st, SvNH, Swerdnaneb, Swisswiss, Syzygos, TACJ, Ta bu shi da yu, Tar7arus, Tassedethe, Taylorsimpson, TechnoLuddite, Teeesssyyy, TeleComNasSprVen, Tesscass, Tesseract2, That Guy, From That Show!, Thaurisil, The Anome, The Disco King, The Transhumanist, The Transhumanist (AWB), TheProject, Thumperward, Thunderbrand, Timberframe, Time for action, Timwi, Tiresias BC, Tobias Bergemann, Tobyk777, Tom X. Tobin, TomAdmirer, Tomvasseur, Tony1, Tothebarricades.tk, Toussaint, Tpbradbury, Travelbird, Treisijs, Trevor MacInnis, Trilobitealive, Trovatore, Trutharchitect, Tyciol, User2004, Uthbrian, VBGFscJUn3, VCK1990, VRmanoj, Vanished user 5zariu3jisj0j4irj, Varano, Veinor, Versus22, Vibrotranshuman, Vicki Rosenzweig, Violetriga, Viznut, Vulcan100, Vvitor, WaldemarIngdahl, Warrickball, Wasp apologist, Wavelength, WesleyDodds, Whateley23, Wikigoodnews, Wile E. Heresiarch, Will Beback Auto, William M. Connolley, Wimt, Winckle, Winged Cat, Woland1234, Wolf530, Woohookitty, Wormagar, Wrayth, Wrp103, Xaonon, Xen0phile, Xyzzyplugh, Yamara, Yanksox, Ynyrhesolaf, Yobmod, Zafiroblue05, Zanimum, Zazaban, Zekkelley, Zenohockey, Zerodegree, 934 anonymous edits

Outline of transhumanism *Source*: http://en.wikipedia.org/w/index.php?oldid=515162885 *Contributors*: "alyosha", Adamawp, Alan Liefting, Auroranorth, Banno, Bsteve7, CaroleHenson, Christine T, Ckatz, David Kernow, Decstop, FoCuSandLeArN, Gurch, Harold Lockworth, Ian.thomson, Jeraphine Gryphon, Joffeloff, Kumioko (renamed), Loremaster, LouScheffer, MadCow257, Megamedo, Mogism, Nexus Seven, Nooper, Paranoid, Pereant antiburchius, Renamed user 39932kk3, Rjwilmsi, Robert Skyhawk, SchreiberBike, TeleComNasSprVen, The Transhumanist, The Transhumanist (AWB), Toussaint, Wikignome0529, Winged Cat, Woohookitty, Yworo, Zhitelew, 16 anonymous edits

Image Sources, Licenses and Contributors

Image:PPTMooresLawai.jpg *Source*: http://en.wikipedia.org/w/index.php?title=File:PPTMooresLawai.jpg *License*: Creative Commons Attribution *Contributors*: Courtesy of Ray Kurzweil and Kurzweil Technologies, Inc.

Image:ParadigmShiftsFrr15Events.svg *Source*: http://en.wikipedia.org/w/index.php?title=File:ParadigmShiftsFrr15Events.svg *License*: Creative Commons Attribution *Contributors*: Tkgd2007

Image:GFO taxonomy tree.png *Source*: http://en.wikipedia.org/w/index.php?title=File:GFO_taxonomy_tree.png *License*: Creative Commons Attribution-Sharealike 3.0 *Contributors*: Original uploader was Leechuck at en.wikipedia

Image:Hierarchical-control-system.svg *Source*: http://en.wikipedia.org/w/index.php?title=File:Hierarchical-control-system.svg *License*: Creative Commons Attribution 3.0 *Contributors*: user:Pbroks13

File:ParseTree.svg *Source*: http://en.wikipedia.org/w/index.php?title=File:ParseTree.svg *License*: Public Domain *Contributors*: Traced by User:Stannered

File:Kismet robot at MIT Museum.jpg *Source*: http://en.wikipedia.org/w/index.php?title=File:Kismet_robot_at_MIT_Museum.jpg *License*: GNU Free Documentation License *Contributors*: User:Tsca.bot, User:Waldir, user:Polimerek

File:Artificial neural network.svg *Source*: http://en.wikipedia.org/w/index.php?title=File:Artificial_neural_network.svg *License*: Creative Commons Attribution-ShareAlike 3.0 Unported *Contributors*: en:User:Cburnett

File:Automated online assistant.png *Source*: http://en.wikipedia.org/w/index.php?title=File:Automated_online_assistant.png *License*: Attribution *Contributors*: Mikael Häggström

File:PPTSuperComputersPRINT.jpg *Source*: http://en.wikipedia.org/w/index.php?title=File:PPTSuperComputersPRINT.jpg *License*: Creative Commons Attribution *Contributors*: Courtesy of Ray Kurzweil and Kurzweil Technologies, Inc.

File:Wikitude.jpg *Source*: http://en.wikipedia.org/w/index.php?title=File:Wikitude.jpg *License*: Creative Commons Attribution-Sharealike 3.0 *Contributors*: Mr3641

File:AR EdiBear0001390 1.jpg *Source*: http://en.wikipedia.org/w/index.php?title=File:AR_EdiBear0001390_1.jpg *License*: Creative Commons Attribution-Sharealike 3.0 *Contributors*: User:Okseduard

File:Image-AR TD0.jpg *Source*: http://en.wikipedia.org/w/index.php?title=File:Image-AR_TD0.jpg *License*: Public Domain *Contributors*: Bukk, MichaelMaggs, Serg3d2, Tryphon, Was a bee

File:MediatedReality on iPhone2009 07 13 21 33 39.jpg *Source*: http://en.wikipedia.org/w/index.php?title=File:MediatedReality_on_iPhone2009_07_13_21_33_39.jpg *License*: Creative Commons Attribution-Sharealike 3.0 *Contributors*: Glogger

File:White Matter Connections Obtained with MRI Tractography.png *Source*: http://en.wikipedia.org/w/index.php?title=File:White_Matter_Connections_Obtained_with_MRI_Tractography.png *License*: Creative Commons Attribution 2.5 *Contributors*: Xavier Gigandet et. al.

Image:DTI-sagittal-fibers.jpg *Source*: http://en.wikipedia.org/w/index.php?title=File:DTI-sagittal-fibers.jpg *License*: Creative Commons Attribution-ShareAlike 3.0 Unported *Contributors*: Thomas Schultz

File:Braitenberg.jpg *Source*: http://en.wikipedia.org/w/index.php?title=File:Braitenberg.jpg *License*: GNU Free Documentation License *Contributors*: Original uploader was Rxke at en.wikipedia

Image:Cajal actx inter.jpg *Source*: http://en.wikipedia.org/w/index.php?title=File:Cajal_actx_inter.jpg *License*: Public Domain *Contributors*: Male1979, Stan Shebs

Image:Science-symbol-13a.svg *Source*: http://en.wikipedia.org/w/index.php?title=File:Science-symbol-13a.svg *License*: Creative Commons Attribution-Sharealike 3.0 *Contributors*: Psychoslave

Image:Ideal feedback model.svg *Source*: http://en.wikipedia.org/w/index.php?title=File:Ideal_feedback_model.svg *License*: Public Domain *Contributors*: Me (Intgr)

Image:James Watt.jpg *Source*: http://en.wikipedia.org/w/index.php?title=File:James_Watt.jpg *License*: Public Domain *Contributors*: Shizhao, Voyager

Image:JohnvonNeumann-LosAlamos.gif *Source*: http://en.wikipedia.org/w/index.php?title=File:JohnvonNeumann-LosAlamos.gif *License*: Public Domain *Contributors*: LANL

Image:Honda ASIMO Walking Stairs.JPG *Source*: http://en.wikipedia.org/w/index.php?title=File:Honda_ASIMO_Walking_Stairs.JPG *License*: Public Domain *Contributors*: Indolences, Morio, Ronaldino, Wst

Image:JARVIK 7 artificial heart.jpg *Source*: http://en.wikipedia.org/w/index.php?title=File:JARVIK_7_artificial_heart.jpg *License*: Public Domain *Contributors*: National Heart, Lung and Blood Institute (NHLBI)

File:Dendrite (PSF).svg *Source*: http://en.wikipedia.org/w/index.php?title=File:Dendrite_(PSF).svg *License*: Creative Commons Zero *Contributors*: Marekich

File:Neural network.svg *Source*: http://en.wikipedia.org/w/index.php?title=File:Neural_network.svg *License*: Creative Commons Attribution *Contributors*: Dake, Mysid

File:IDA Cognitive Architecture.jpg *Source*: http://en.wikipedia.org/w/index.php?title=File:IDA_Cognitive_Architecture.jpg *License*: Creative Commons Attribution-Sharealike 3.0 *Contributors*: Graeme E. Smith

File:ArtificialNeuronModel.png *Source*: http://en.wikipedia.org/w/index.php?title=File:ArtificialNeuronModel.png *License*: Creative Commons Attribution-ShareAlike 3.0 Unported *Contributors*: Chrislb

File:Action potential propagation animation.gif *Source*: http://en.wikipedia.org/w/index.php?title=File:Action_potential_propagation_animation.gif *License*: Creative Commons Attribution-Share Alike *Contributors*: John Schmidt

File:User-FastFission-brain.gif *Source*: http://en.wikipedia.org/w/index.php?title=File:User-FastFission-brain.gif *License*: GNU Free Documentation License *Contributors*: User:Solipsist

File:Connectome extraction procedure.jpg *Source*: http://en.wikipedia.org/w/index.php?title=File:Connectome_extraction_procedure.jpg *License*: Creative Commons Attribution 3.0 *Contributors*: Hagmann P, Cammoun L, Gigandet X, Meuli R, Honey CJ, et al

File:Magnetoencephalography.png *Source*: http://en.wikipedia.org/w/index.php?title=File:Magnetoencephalography.png *License*: Public Domain *Contributors*: Original uploader was Tom Holroyd at en.wikipedia

File:C.elegans-brain-network.jpg *Source*: http://en.wikipedia.org/w/index.php?title=File:C.elegans-brain-network.jpg *License*: Creative Commons Attribution-Sharealike 3.0,2.5,2.0,1.0 *Contributors*: Mentatseb

Image:Systems thinking about the society.svg *Source*: http://en.wikipedia.org/w/index.php?title=File:Systems_thinking_about_the_society.svg *License*: Creative Commons Attribution 3.0 *Contributors*: Marcel Douwe Dekker (Mdd)

Image:Henk Bikker 1991.jpg *Source*: http://en.wikipedia.org/w/index.php?title=File:Henk_Bikker_1991.jpg *License*: Creative Commons Attribution-Sharealike 3.0,2.5,2.0,1.0 *Contributors*: Marcel Douwe Dekker (Mdd)

File:Genomics GTL Pictorial Program.jpg *Source*: http://en.wikipedia.org/w/index.php?title=File:Genomics_GTL_Pictorial_Program.jpg *License*: Public Domain *Contributors*: Mdd

File:Signal transduction pathways.svg *Source*: http://en.wikipedia.org/w/index.php?title=File:Signal_transduction_pathways.svg *License*: GNU Free Documentation License *Contributors*: cybertory

File:Biology organism collage.png *Source*: http://en.wikipedia.org/w/index.php?title=File:Biology_organism_collage.png *License*: Creative Commons Attribution-Sharealike 3.0 *Contributors*: Azcolvin429

File:Tree of life by Haeckel.jpg *Source*: http://en.wikipedia.org/w/index.php?title=File:Tree_of_life_by_Haeckel.jpg *License*: Public Domain *Contributors*: G.dallorto, Geniac, Grook Da Oger, Julia W, Mogelzahn, Nguyên Lê, Ragesoss, Sct72, UpstateNYer

Image:Epithelial-cells.jpg *Source*: http://en.wikipedia.org/w/index.php?title=File:Epithelial-cells.jpg *License*: GNU Free Documentation License *Contributors*: Dbc334, Duesentrieb, GeorgHH, Helix84, JWSchmidt, Martin H., ViperSnake151, Was a bee, 2 anonymous edits

File:Mutation and selection diagram.svg *Source*: http://en.wikipedia.org/w/index.php?title=File:Mutation_and_selection_diagram.svg *License*: GNU Free Documentation License *Contributors*: Elembis

Image:Punnett square mendel flowers.svg *Source*: http://en.wikipedia.org/w/index.php?title=File:Punnett_square_mendel_flowers.svg *License*: Creative Commons Attribution-ShareAlike 3.0 Unported *Contributors*: Madprime

Image:ACTH Negative Feedback.svg *Source*: http://en.wikipedia.org/w/index.php?title=File:ACTH_Negative_Feedback.svg *License*: Creative Commons Attribution 3.0 *Contributors*: DRosenbach

File:Energy and life.png *Source*: http://en.wikipedia.org/w/index.php?title=File:Energy_and_life.png *License*: Public Domain *Contributors*: Mikael Häggström

Image:biological cell.svg *Source*: http://en.wikipedia.org/w/index.php?title=File:Biological_cell.svg *License*: Creative Commons Attribution-Sharealike 2.5 *Contributors*: MesserWoland Szczepan1990

File:Phylogenetic tree.svg *Source*: http://en.wikipedia.org/w/index.php?title=File:Phylogenetic_tree.svg *License*: unknown *Contributors*: This vector version: Eric Gaba (Sting - fr:Sting)

Image:Biological classification L Pengo.svg *Source*: http://en.wikipedia.org/w/index.php?title=File:Biological_classification_L_Pengo.svg *License*: Public Domain *Contributors*: Peter Halasz. (User:Pengo)

image:Common clownfish.jpg *Source*: http://en.wikipedia.org/w/index.php?title=File:Common_clownfish.jpg *License*: Public domain *Contributors*: Janderk

File:h+ Cover 1.jpg *Source*: http://en.wikipedia.org/w/index.php?title=File:H+_Cover_1.jpg *License*: unknown *Contributors*: Loremaster, Quibik, Tpbradbury, 1 anonymous edits

File:PPTCountdowntoSingularityLog.jpg *Source*: http://en.wikipedia.org/w/index.php?title=File:PPTCountdowntoSingularityLog.jpg *License*: Creative Commons Attribution *Contributors*: Coutesy of Ray Kurzweil and Kurzweil Technologies, Inc.

File:Converging technologies.png *Source*: http://en.wikipedia.org/w/index.php?title=File:Converging_technologies.png *License*: Public Domain *Contributors*: Ignacio Icke, Marekich

File:Biocomplexity spiral.jpg *Source*: http://en.wikipedia.org/w/index.php?title=File:Biocomplexity_spiral.jpg *License*: Public Domain *Contributors*: Grafite, Pieter Kuiper, StN

File:Amish vs modern transportation.jpg *Source*: http://en.wikipedia.org/w/index.php?title=File:Amish_vs_modern_transportation.jpg *License*: Creative Commons Attribution-ShareAlike 3.0 Unported *Contributors*: Nils Fretwurst / Foto: Nils Fretwurst

License